EXPERIMENTING
with the
PICBASIC PRO
COMPILER

Les Johnson

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PICBASIC PRO COMPILER

BY LES JOHNSON.

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The author has no connection to microEngineering, Labs Inc or Microchip Technologies.

Introduction

The BASIC language has been popular since it's conception in the 1970's. One of the main reasons for this is its ease of use and ability to make a project work within a matter of hours, instead of days or weeks. But to have the ability to program a microcontroller in BASIC, is a dream come true. Moreover, when the BASIC language is in the form of a compiler; it combines both speed and ease of use. MicroEngineering, Labs Inc have come up with the perfect medium for programming the PICmicro range of microcontrollers. The PicBasic Pro Compiler allows total control over the full range of 14-bit and 16-bit core PIC's available.

This book takes over from where the compiler's user manual left off, and is intended for use by the more adventurous programmer. It illustrates how to control readily available devices such as Analogue to Digital Converters, Digital to Analogue Converters, Temperature sensors etc, that may be incorporated into your own projects, as well as some complete projects. In addition, tips and techniques are discussed which allow even more control over the PIC. Each experiment in the book has an accompanying program that shows exactly what is happening, or supposed to happen. Most are in the form of subroutines, ready to drop into your own program.

The majority of the projects will work on any of the 14-bit core devices, however, unless otherwise stated, the PIC used is the ever popular PIC16F84 using a 4mHz crystal.

The accompanying CDROM has all the source listings for the experiments, as well as the manufacturers datasheets and application notes for the semiconductor devices used.

My thanks go to Jeff Shmoyer, not only for co-writing the compilers, but also for his advice in the construction of this book. I would also like to thank you for purchasing this book and I wish you every success in your future projects.

Les Johnson.

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Simple serial LCD controller

Intelligent LCD modules accept data and command instructions over a four or eight bit parallel interface. Command instructions include: cursor control, clearing, scrolling, etc. These commands are described in the LCD module data sheet and in the compiler's manual. Thanks to the LCDOUT command, these displays are not difficult to use, but still require at least six precious pins from the PIC to be used. The serial LCD controller described here, simplifies the use of these displays even more, by enabling control of the LCD with a single wire. This is invaluable in debugging your latest masterpiece, as it opens up a window into your code. By connecting it to an unused pin and using the DEBUG command at specific areas within the program, variables and registers can be viewed.

The program **SER_LCD.BAS** implements a simple serial LCD controller for use with the PIC16F84.

When the PIC is powered up, the first thing It does is turn on the LCD and wait the appropriate time for the display to be fully initialised, this usually takes approximately 100ms. It then looks at the polarity switch, and jumps to the appropriate section of code and displays: -

> *"T9600 Baud OK!"*   *for true input*
> *or*
> *"N9600 Baud OK!"*   *for inverted input*

It then waits for a 9600-baud serial character of whichever polarity was chosen. If the character is a special escape character (*254*), the next character is assumed to be a command. The PIC will therefore pass the following byte to the LCD as a command. Otherwise, the data will pass directly to the LCD. This allows the display to be cleared scrolled, etc. simply by sending data with an escape character in front of the control byte: -

> *Serout PortB.0,N9600,[254,1]*
> *Pause 30*

This will clear the LCD. Note the PAUSE command, this gives the LCD module time to recover from the CLS command before sending another character.

If a display with more or less than 2 lines is used then alter the last line of the LCD defines: -

Define LCD_LINES   2   ' Set number of lines on Display

Figure1.1 shows the circuit of the Simple serial LCD controller. Serial data enters through R5, this gives some protection to the PIC in the event of a short circuit, it is also connected to one terminal of the DIL switch (*SW1*).

The DIL switch serves two purposes, first it configures the serial polarity mode (*inverted or true*) by pulling PortB.4 to ground through R3, just enough to register as a low reading (*0*), but not enough to interfere with the output to the LCD. Sharing a pin like this is a common practice when spare pins are not available.

Secondly, it stops the input from floating, (*floating means that the pin is neither set high or low*). This is achieved by resistors R2 and R4. When the polarity is configured for inverted mode, the left switch in the DIL package is closed, which means that the right switch is open, thus allowing only R4 to be connected to the input, this pulls the serial input pin slightly towards ground. And when true polarity is selected, the left switch in the DIL package is open and the right switch is closed, bringing R2 into circuit, but as R2 has a lower resistance than R4 the serial input pin is pulled more to the supply line. Without these resistors, random characters would be displayed when the input was not connected to anything.

Figure1.1. Simple serial LCD controller.

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Multiple Baud Serial LCD controller

If, like me, you are fascinated by serial (*RS232*) communication, then this project is a must. The baud rates are selectable from 300 to 19200 and both inverted and non-inverted serial data is accepted. The circuit is, in essence the same as the Simple controller, but with the exception of a clever little switch called a *Decimal Rotary DIL*, figure1.2 shows the pinout of one of these devices. It has ten rotary positions, numbered 0 to 9, and these numbers are represented as BCD outputs on pins, 1, 2, 4 and 8.
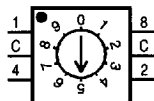
Figure1.2.

The outputs of the switch are connected to RB0 - RB4, and by looking at these inputs, the program is able to determine which baud rate is required i.e.
3 for 300 baud, 9 for 9600, 8 for 19200 (*position 1 is already used*) etc.

Figure1.3 shows the circuit for the multi-baud controller. Because of the higher baud rates involved, a 16F873 running at 12mHz is used.

You may have noticed that the Vdd pin of the LCD is connected to PortB.5 instead of the supply line, this is so that when the PIC is reset, all ports are initialised as inputs by default, thus, also turning off the LCD, and effectively resetting it. Therefore, the first thing the program does is make PortB.5 an output, and turn the LCD on.

In order to read the rotary dil switch, the internal pullup resistors are enabled on PortB, and the lower 4-bits are made inputs, we are only interested in the pins that the switch is connected to, so the port is read and the upper 4-bits are masked out by ANDing the result with %00001111, the value held in **B_TEST** now holds the BCD output of the switch. A lookup table is setup by using the LOOKUP command which holds all the baud rates that will be selected (*0-9*), they have already been divided by 100 (*12 instead of 1200, 96 instead of 9600*), this is because the calculation to set the baud rate for SERIN2 is, (*1000000 / baud*)- 20, however, this is too large a number for the compiler to handle, therefore, it has to be scaled down, this is achieved by dividing by 100 i.e. (*10000 / (baud / 100)) - 20*. After the LOOKUP command, the variable **BAUD** holds the selected baud rate/100, then the above calculation is carried out, and **BAUD** now holds the value to be placed in the SERIN2 command.

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To read the polarity switch, PortB.4 is made an input and bit-14 of **BAUD** is set or cleared according to the result. Bit-14 is the mode setting, (*1 = Inverted, 0 = non inverted*): -

```
TrisB.4=1              ' Set PortB.4 to Input
If P_Test=1 then       ' If P_Test is high then Set for True Polarity
Baud.14=0              ' Reset bit-14 (Mode bit, clear for True)
Mode="T"              ' Variable used for the display
Else                   ' Else Set for Inverted Polarity
Baud.14=1             ' Set bit-14 (Mode bit, set for Inverted)
Mode="N"             ' Variable used for the display
Endif
TrisB.4=0              ' Turn PortB.4 back to an output
```

The incoming serial data is then read in using the SERIN2 command, as this can achieve higher baud rates than SERIN. The program now sits in a loop, receiving data and outputting it to the LCD. If the control byte is detected (*254*) the program is re-directed to a routine that input's another serial character, this will be the byte that informs the LCD as to what action should be taken, scroll, clear screen etc:-

```
Loop:
    Serin2 SI,Baud,[RcvByte]        ' Receive the serial byte
    If RcvByte=254 then Control     ' Trap the control byte
    Lcdout RcvByte                  ' Else display it on the LCD
    Goto Loop                       ' Keep on looking

Control:
    Serin2 SI,Baud,[RcvByte2]       ' Receive the second serial byte
    If RcvByte2=253 then goto Bar   ' Trap the Bargraph byte
    Lcdout RcvByte,Rcvbyte2         ' Or send out the two bytes
    Goto Loop                       ' Look again

Bar:
' Receive the Third and fourth serial byte
    Serin2 SI,Baud,[Bar_Pos,Bar_Val]
    Lcdout      I,Bar_Pos           ' Position of bargraph
    Gosub Bargraph                  ' Display the bargraph
    Goto Loop                       ' Look again
```

Multiple baud serial LCD controller
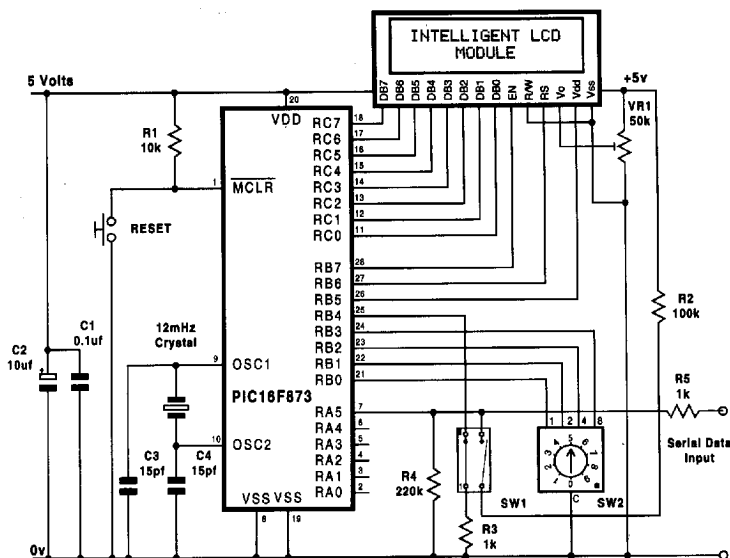
Figure1.3. Multi-baud serial controller.

Bargraph option

The Bargraph display is initiated by sending the control byte 253 along with the position to start displaying from, and then the length of the bar: -

I	Con	254	' Control Byte
Bar	Con	253	' Bar display initiate
Line1	Con	128	' Display line 1

3.6 Volts
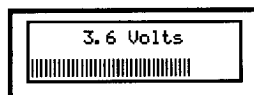
Debug I , Bar , Line1 , Length_of_Bar : Pause 1

'Length_of_Bar' may be a value of 0 to 59 if a 4x20 display is used, or a value of 0 to 47 for a 2x16 display. The PAUSE command allows the serial controller time to do the bargraph subroutine.

The Bargraph subroutine is in the form of an include file, which is loaded in after the LCD has initialised. The include file **BARGRAF2.INC** is for use with a 2x16 LCD, and **BARGRAF4.INC** is for a 4x20 LCD. The code is fully commented. The serial controller program **MULTILCD2.BAS** is for use with 2x16 LCD modules, and program **MULTILCD4.BAS** is for use with 4x20 LCD modules. The program **SER_TEST.BAS** demonstrates the use of the bargraph option.

Contrast control for an LCD module

If a contrast control is needed, it is simple enough to add a small preset potentiometer connected to the *Vo* pin of the LCD, as in figure1.4.

Contrast increases as the pot is turned towards ground and the voltage on Pin *Vo* decreases. Alternately, a fixed resistor with a value of a few hundred ohms can be connected from *Vo* to ground.

GND Figure1.4. LCD Contrast control.
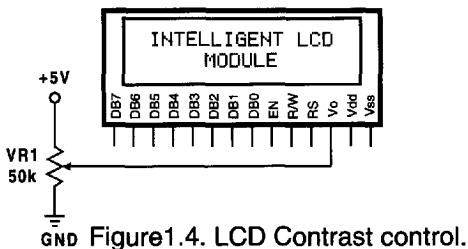
Extended-temperature LCD modules on the other hand, require a negative voltage applied to pin Vo, this can be achieved with a switch-mode negative voltage converter, such as the MAXIM ICL7660. As shown in figure1.5.
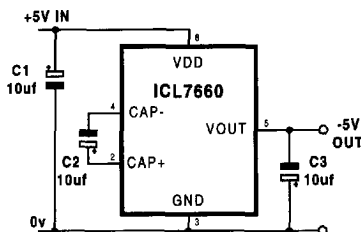
Figure1.5. Switch-mode negative voltage generator.

Driving multiplexed 7-segment LED displays

The main consideration when designing an interface to an LED display is the number of pins available on the PIC. To drive a five digit non-multiplexed display would require a PIC with 45 I/O pins, one for each segment. This is of course impractical therefore, multiplexing is almost universally adopted. Which will still take 13 pins, but on the larger PICs with 33 I/Os this is not usually a problem.

As most of you will already know, multiplexing is accomplished by driving each display in sequence. As each display is turned on, the segment data from the PIC is set to the correct pattern for that digit. The patterns for each digit are shown in table 1.1.

Digit Displayed	Binary value on A-G segments							Decimal
	G	F	E	D	C	B	A	
0	0	1	1	1	1	1	1	63
1	0	0	0	0	1	1	0	6
2	1	0	1	1	0	1	1	91
3	1	0	0	1	1	1	1	79
4	1	1	0	0	1	1	0	102
5	1	1	0	1	1	0	1	109
6	1	1	1	1	1	0	0	124
7	0	0	0	0	1	1	1	7
8	1	1	1	1	1	1	1	127
9	1	1	0	0	1	1	1	103

Table 1.1. Binary pattern for 7-segment digits.

To illustrate how a single digit is displayed, we will look at digits 4 and 5. The binary pattern for digit 4 is %01100110, and for digit 5 it is %01101101. Figure1.6 shows how these binary patterns relate to the segments to illuminate.
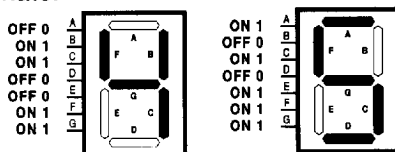
Figure1.6. Binary relationship to illuminated segments.

Remember, that the 'A' segment is attached to the LSB of the binary number.

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Connecting the display to the PIC is uncomplicated. The A-segment connects to PortC bit-0, and the G-segment connects to PortC bit-6. Segments B..F connect to the pins in between. The decimal point is connected to bit-7 of the same port.

In this demonstration, we shall be using common cathode displays. As the name suggests, all the cathodes for the individual segment LEDs are connected together internally, as shown below in figure1.7.
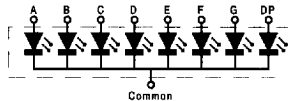
Figure1.7. Individual LEDs within a common cathode display.

By examining figure1.7 we can see that applying approx 2V to the anode of a particular segment LED, while the common line is connected to ground an individual segment may be illuminated.

To multiplex more than one display, requires us to take control of their individual cathodes. This is achieved by a transistor acting as a switch, as shown in figure1.8.
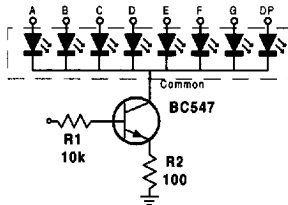
Figure1.8. Transistor switch.

A logic high on the base of the transistor will switch it on, thus pulling the common cathodes to ground. R2 limits the current that can flow between the individual segment LEDs. R1 limits the voltage supplied to the base of the transistor.

We now have the means to switch each display on in turn, as well as the information required to illuminate a specific digit. What's required now is a means of turning on a display, illuminate the correct digit and do the same thing for the next ones, quickly enough to fool the eye into thinking it is seeing all the displays illuminated at once.

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And all within the background, to allow the program to process the actual information to be displayed. This is a perfect application for a TMR0 interrupt using the compiler's ON INTERRUPT command.

Program **5CC_DISP.BAS** shows a way of displaying a five-digit number on five, 7-segment displays. Because the five displays require 13 I/O pins, the program is intended to be used on one of the newer 16F87X range of PICs, and also assumes a 20mHz oscillator is being used. Figure1.10 shows the circuit layout for the demonstration.

The first thing the program does is initiate a TMR0 interrupt (*as shown in the programming techniques section*) to generate an interrupt every 1.6384*ms*, by setting the prescaler to 1:32. To calculate the repetitive rate of the interrupt use the following formula: -

Interrupt rate (in us) = ((OSC / 4) * 256) * prescaler ratio

Within the interrupt handler routine, the digit of interests pattern is extracted by using the LOOKUP command, where a specific pattern corresponds to a certain number held in the array **NUM[O_C]**. The pattern extracted from the lookup table is placed into the variable **DISP_PATT**. The variable **O_C** has a dual purpose; its main purpose is to form a sort of *time-share* for the individual displays. On each interrupt, the variable **O_C** is incremented, and each display waits for its particular time-slot before it is turned on. This way each display is turned on for approx 1.6ms spread over five interrupts, causing an overall scan rate of about 125Hz.

Within each display's time-slot, the previous display is turned off and the value held in **DISP_PATT** is placed onto PortC. A check is then made of the variable **DP** which holds the decimal point placement. If **DP** holds the value of the display we are currently using, the decimal point is turned on by setting bit-7 of PortC. The display itself is then turned on by setting the particular bit of PortB high. Note. **DP** may hold a value between 0..5 where 1 is the farthest right display, and zero disables the decimal point.

While the interrupt gives us a means of displaying five digits, the subroutine **DISPLAY** does the processing of the actual number to display. The subroutine first disables the interrupt to eliminate any glitches that may be visible while processing the numbers, then it splits

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the individual digits from the 16-bit number held in **D_NUMBER** using the DIG operand. Each digit is placed into the five element array **NUM**, and a series of *if-then's* zero suppress the unused digits. After all the digits have been processed, the interrupt is re-enabled and the subroutine is exited.

To aid in the use of multiplexing the displays, several include files have been developed for use with 2 to 5 displays. The include file of choice should be placed at the top of the program after the **MODEDEFS.BAS** file has been included.

The include file **5CC_DISP.INC** is for use when 5 displays are required The TMR0 interrupt will automatically be enabled upon the program's start. It also contains the subroutine **DISPLAY** which expects two variables to be pre-loaded before it is called. The first variable, **D_NUMBER** holds the 16-bit value to be displayed. The second variable, **DP** holds the position of the decimal point (*0..5*): -

```
D_NUMBER = 12345        ' Display the number 12345
DP = 0                  ' Do not place the decimal point
Gosub Display           ' Display the number
```

The include file **4CC_DISP.INC** is for use when 4 displays are required. Again, the TMR0 interrupt is enabled on the program's start. The same two variables need to be pre-loaded before the **DISPLAY** subroutine is called. However, **DP** now has the range 0..4.

The include files **3CC_DISP.INC** and **2CC_DISP.INC** are for use with 3 and 2 displays respectively.

The variables, **D_NUMBER** and **DP** are already pre-declared within the include file, therefore, there is no need to declare them in your program.

The program **DISP_TST.BAS** demonstrates the use of 2 to 5 multiplexed displays, by uncommenting the required include file. The program increments a 16-bit variable, which is displayed on the 7-segment LEDs. However, this loop could easily be replaced by the ADCIN command for displaying the voltage converted. Or a temperature reading routine.

Substituting Common Anode displays

If common anode displays are substituted for the common cathode types then a slight re-arrangement of the switching transistors is required, as shown in figure1.9.
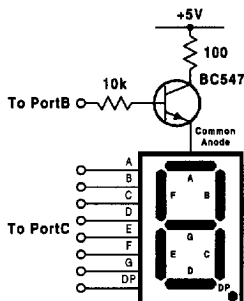
Figure1.9. Common Anode display.

A slight difference in the code is also required. The main difference is the patterns that make up the digits. When common cathodes were used, a high on the segments illuminated them, but for common anodes, a low on the segments is required. Therefore, the patterns shown in table 1.1 need to be inverted i.e. %11111100 becomes %00000011. This can easily be achieved by placing new values into the LOOKUP command within the interrupt handler. The new patterns are shown below: -

 [192,249,164,176,153,146,131,248,128,152,255]

One other thing that requires altering is the decimal point placement. Previously PortC.7 was set high to turn on the point, but now it needs to be pulled low. This again is easily remedied simply by changing the lines corresponding to PortC.7 in the interrupt handler.

All the previous programs and include files discussed have already been altered for use with common anode displays and may be found in the **COM_ANOD** folder.

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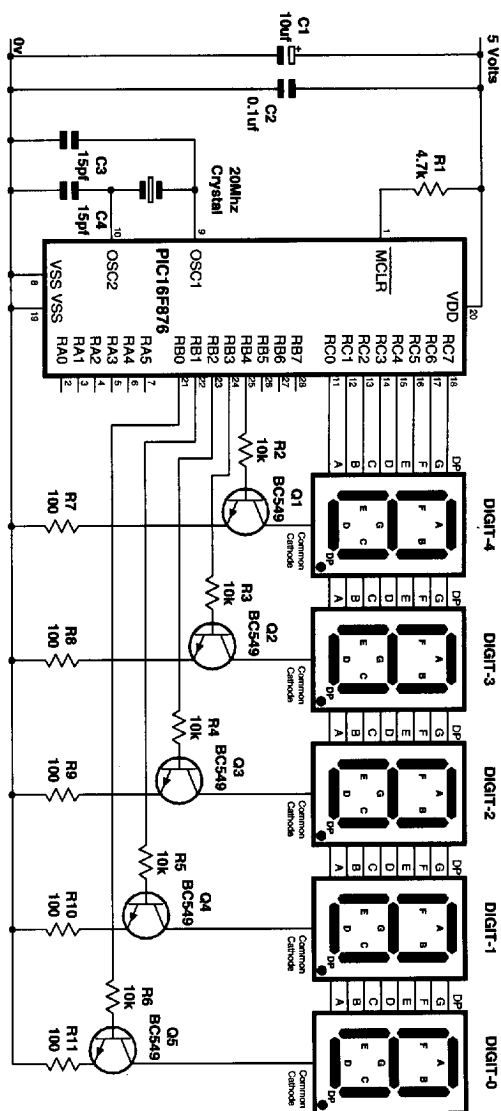
Figure1.10. 5-digit multiplexed common cathode display.

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When using the multiplexer in your own program, you must remember that it is using the compiler's ON INTERRUPT command. And as such the precautions and work-arounds explained in the *programming techniques section* should be observed.

If an oscillator of less than 20mHz is required, then the prescale value of the interrupt should be decreased. Especially if more than four digits are being utilized, otherwise a slight flickering of the display will be noticed.

This is easily accomplished by changing the three lines in the include files that control the PS0, PS1, and PS2 bits of OPTION_REG. For example, to use a 4mHz oscillator with a five digit display, the following changes should be made: -

> *PS0 = 0*
> *PS1 = 1*
> *PS2 = 0*   *' Assign a 1:8 prescaler to TMR0*

By examining the include files for the different amount of multiplexed displays, you will notice that as the amount of displays is reduced then the interrupt rate is also decreased. The main reason for this is that, as the interrupt handler is processing its multiplexing code, the main program is halted until the interrupt is over, thus ultimately slowing it down. The less times an interrupt handler needs to be called the quicker the main program becomes.

A final note on multiplexing: When reducing the amount of displays used, always remove the most significant digits. For example, if 4 displays are used instead of 5 then remove display number 4, which is the leftmost digit.

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Program - MAX_CNT.BAS

Interfacing to the MAX7219

The MAX7219 is capable of driving up to eight common-cathode seven-segment LED displays using a three wire (*synchronous serial interface*). It can also convert binary-coded decimal (*BCD*) values into their appropriate patterns of segments. And has built-in pulse-width modulation and current-limiting circuits to control the brightness of the displays with only a single external resistor.

With eight LED displays attached, the MAX7219 is able to scan them at over 1200Hz, thus preventing any display flicker. If a display of less than eight LEDs is used, the chip may be configured to scan only the one's connected, increasing the brightness and scanning frequency of the display. With all of its complexity one would expect the MAX7219 to be difficult to control, but quite the opposite is true. With just a few lines of code a versatile LED display can be realized and with only three pins (*data in, clock, and load*) required on the PIC, even the 8-pin devices may be used.

Connection to the LED displays is straightforward, pins SEG-A through SEG-G and SEG DP-connect to segments A through G and the decimal point of all of the common-cathode displays. Pins DIGIT-0 through DIGIT-7 connect to the cathodes of each of the displays. Figure1.10 shows a typical setup using four LED displays, interfaced in this case with a PIC16F84.

Resistor R2 sets the current through each LED display. The smaller this resistor is, the greater the current through each segment (*minimum value =9.53kΩ*), a value of 10kΩ sets the current to 40mA per display. R3 is a pulldown resistor on the interface between the PIC and the MAX7219 LOAD pin, this is required because when a PIC resets, its ports are initialised as inputs. They are effectively disconnected, therefore, anything connected to them is also disconnected, and are floating. Such inputs frequently float high, however, electrical noise can cause them to change states at random, this will normally cause the MAX7219 to go into test mode with all segments lit. Therefore, R3 prevents this by pulling the load pin more to ground when not in use.

Figure1.10. MAX7219 LED display controller.

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There are 14 addressable registers within the MAX7219, table 1.1 shows a list of them.

Register	Address	Description
NOP	0	No Operation
Digit 0	1	The first LED Display
Digit 1	2	The second LED Display
Digit 2	3	The third LED Display
Digit 3	4	The fourth LED Display
Digit 4	5	The fifth LED Display
Digit 5	6	The sixth LED Display
Digit 6	7	The seventh LED Display
Digit 7	8	The eighth LED Display
Decode Mode	9	BCD decoding On/Off
Intensity	10	Brightness of Displays
Scan Limit	11	Amount of Displays attached
Shutdown	12	Place chip into Standby
Test	15	Test mode On/Off

Table2.1. Registers within the MAX7219

Digit-0 – Digit-7 point to the relevant displays attached, digit-0 is the far-right display.

Decode enables or disables BCD decoding for each individual display (*%10000001 would enable BCD on displays 0 and 7*).

Intensity sets the overall brightness of the displays (*0 to 15*).

Scan Limit informs the MAX7219 as to how many displays are attached (*0-7*).

Shutdown, places the MAX7219 in standby mode when cleared.

Test, places the MAX7219 in test mode when set to 1 (*maximum brightness and all segments on*).

When sending data to the MAX7219 it expects a packet consisting of a 16-bit word containing the register number and then the value to be placed within the register: -

First byte 11   *points to the scan limit register*
Second byte 3   *informs the MAX that 4 LEDs are being used*

The 16-bits are clocked into the MAX7219, regardless of the state on the LOAD pin. However, they are only acted upon when the LOAD pin is clocked high to low, which has the secondary effect of disabling the device after the data is sent.

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Program **MAX-CNT.BAS** shows a simple application of the MAX7219. In the program, a 16-bit integer held in the variable **COUNTER** is incremented and then decremented, this is displayed on the four 7-segment LEDs. First the MAX7219 is initialised by loading the Scan register with 3 (*4 displays attached*), the Luminance register with 3, Decode register with %00001111, this will configure the first 4 displays to BCD decoding, then the Switch register is set to one, which will wake up the MAX7219 and finally the Test register is cleared.

The count up-down routine then places the position of the decimal point in **MAX_DP**, (*MAX_DP may contain a value between 0...7, zero being the right-most display*), and the value of **COUNTER** into **MAX_DISP**. The subroutine **DISPLAY** is then called, this extracts the separate digits from the variable **MAX_DISP**, using the DIG operand, and displays them on the appropriate LEDs. Note the zero suppression, this is simply a series of *if then's* that blank the digits by sending the value 15 when the display is not being used. This subroutine itself calls another named **TRANSFER**, which shifts out the two bytes then strobes the LOAD pin low then high, this transfers the data into the internal registers of the MAX7219.

If more or less displays are used, change the value placed in **SCAN_REG** (*this is located in the initialisation section of code*), to the appropriate amount of LEDs attached (*0-7*).

Also within the subroutine DISPLAY, change the lines: -

For Position = 4 to 1 step −1

into

For Position = n to 1 step −1

Where *n* is the number of LEDs attached (*1-8*)

If Digit >= 3 then Digit = 0

Into

If Digit >= n then Digit = 0

Where *n* is the number of digits in the variable **MAX_DISP** (*0-4*), in PicBasic Pro the maximum amount of digits is five (*0 to 65535*)

Section-2

Interfacing with Keypads

Keypad interfacing principals.
Interfacing with a 12-button keypad.
Interfacing with a 16-button keypad.
Serial keypad controller.
Receiving data from the keypad controller.
Assembler coded, keypad decoder.
Using the pseudo command, INKEYS.

Experimenting with the PicBasic Pro Compiler

Keypad interfacing principals

Interfacing to a few buttons is simple, but when more are required, a keypad is almost essential. In this experiment, we shall look at the principals of how a keypad works and write a subroutine to access it. Figure 2.1 shows the arrangement of a 12-button and 16-button keypad. As can be seen they are arranged as a matrix, this minimizes the amount of I/O lines needed, otherwise 12 or 16 inputs would have to be used to interface to the same amount of keys. By arranging the keys into Rows and Columns we only require 7 or 8 inputs to operate it, however, the price to pay is that a keypad scanning routine must be employed.
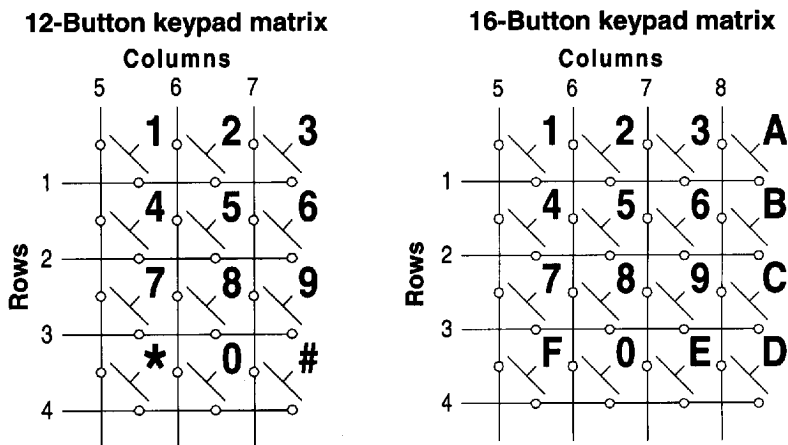
Figure 2.1.

The keypad scanning routine systematically searches for a key press. It starts by setting the connections to the column pins as inputs and the connections to the row pins as outputs. The inputs are held high by the internal pullup resistors. The object of the search is to find out whether one of the rows of the keypad is connected to one of the columns, and if so which one. The scan routine pulls one of the row lines low, then looks at the columns input to see whether a 0 is detected. If not, it then tries the next row; this is continued until all the row lines have been scanned. There are as many keypad scanning routines as there are programmers. Each programmer has his/her way of doing things. However, whichever way gets the job done effectively is OK.

Interfacing with a 12-button keypad

The program **KEYPAD12.BAS**, and the circuit shown in figure 2.2 demonstrate the use of a 12-button keypad. The program scans the keypad and displays the value of the key presses on a serial LCD module connected to PortB.7. It is based around the keypad scanning subroutine **INKEYS**. When this subroutine is called, two variables are returned. The first variable is **KEY**, which holds the value of the key pressed (*128 if no key pressed*), the second variable returned is **DEBOUNCE**, which (*as you might have guessed*) is a debounce flag. This returns holding a zero if a key has been pressed, however, when the **INKEYS** subroutine is called a second time and a key is still in use, a value of one is returned. One possible use of this feature could be: -

Main:
Gosub Inkeys   *'Go scan the keypad*
If Debounce=1 then goto Main   *'Go back if button is still held*

Within the **INKEYS** subroutine the variable **DEBOUNCE** is initially set to 1, then the first four bits of PortA are configured as outputs (*rows*), and the first three bits of PortB are setup as inputs (*columns*). Care has been taken to configure only the relevant bits that the keypad is attached to. The internal weak pullup resistors are enabled and the first row is pulled low (*PortA.3*), the subroutine **SCANCOL** is then called, this examines the column lines in turn and increments the variable **KEY** when a keypress has not been detected, this will build up 13 numbers corresponding the a certain keypress or no keypress (*albeit in the wrong order*). On returning, the variable **K_FLAG** will hold 1 if a keypress was detected otherwise it holds 0. The variable **K_FLAG** is examined after its return, to ascertain whether to scan the next row or to process the value held in **KEY**. If **K_FLAG** returned 0, then the same procedure is carried out for all four rows. However, if **K_FLAG** returned a 1 then the debounce flags are set or cleared accordingly to the value held in **D_FLAG**. The variable **KEY** is re-arranged to correspond to the keypad legends, by using the LOOKUP command: -

' Map of the keypad legends for numeric output
Lookup Key,[1,2,3,4,5,6,7,8,9,10,0,11,128],Key

For example, in its raw state, **KEY** will hold the value 0 if the one key has been pressed, 10 if the zero key has been pressed, and 12 if no keypress has been detected, therefore, the thirteen values within the braces of the LOOKUP command correspond to the raw **KEY** values and the expected keypad legend values.

The program **KEYTST12.BAS** does the same as **KEYPAD12.BAS**, but the **INKEYS** subroutine is loaded in as an include file: -

Include "INKEYS12.INC"   'Place this at the beginning of the program.
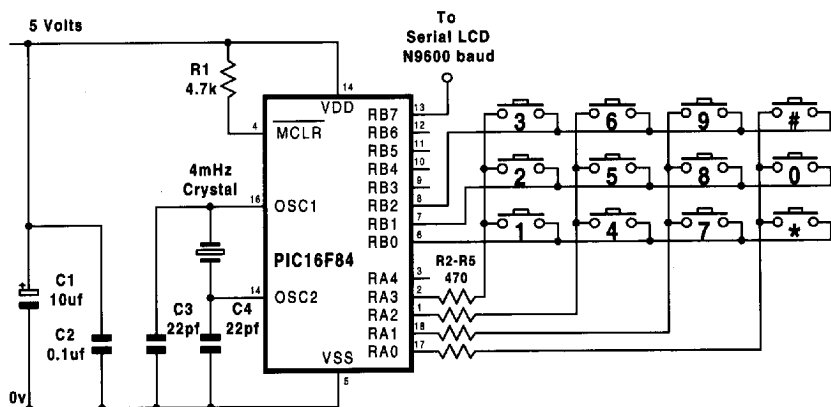
Figure 2.2. 12-button Keypad Circuit.

Experimenting with the PicBasic Pro Compiler

Interfacing with a 16-button keypad

Using a 16-button keypad is essentially the same as using the 12-button version, however, minor differences in the **INKEYS** subroutine have to be made. Figure 2.3 shows the slightly different circuit layout and program **KEYPAD16.BAS** demonstrates its use. The keypad is again arranged as a matrix, but this time it is 4x4, (*four columns and four rows*).

Within the **INKEYS** subroutine most of the code stays the same, it still scans the four rows, but this time there are four columns instead of three. Therefore, one extra input is required which means the TRIS value has to take this into account. As with the 12-button program, the value returned in **KEY** from the subroutine **SCANCOL** does not match up with the legends printed on the keypad's buttons. Therefore, the LOOKUP command is used again to change the value returned in **KEY** to the correct number. However, this time there are 17 different combinations.

' Map of the keypad legends for numeric output
Lookup Key,[15,7,4,1,0,8,5,2,14,9,6,3,13,12,11,10,128],Key

The program **KEYTST16.BAS** does the same as **KEYPAD16.BAS**, but the **INKEYS** subroutine is loaded in as an include file: -

Include "INKEYS16.INC"   *'Place this at the beginning of the program.*
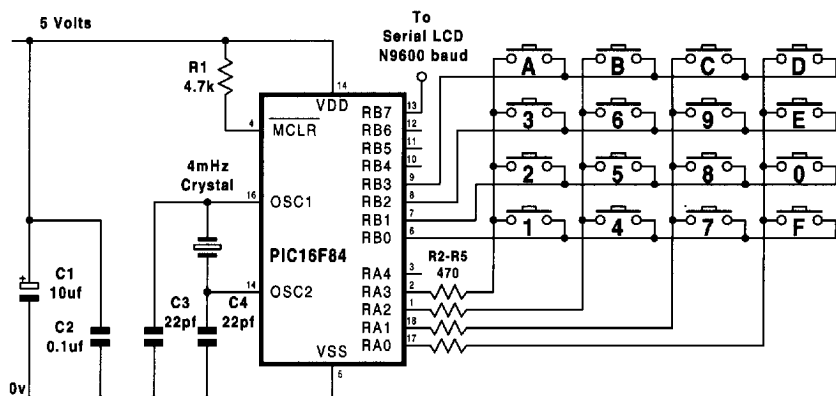
Figure 2.3. 16-button Keypad Circuit.

Experimenting with the PicBasic Pro Compiler

In both the 12 and 16 button demonstration programs, the value returned in the variable **KEY** is a numeric representation of the key pressed (*i.e. key one returns the value 1*). However, if the ACSII representation is desired (*i.e. key one returns the value 49*), the commented LOOKUP command needs to be uncommented and the initial LOOKUP command needs to be commented.

' *Map of the 12-button keypad legends for ASCII output*
  Lookup Key,["1","2","3","4","5","6","7","8","9","*","0","#",32],Key

' *Map of the 16-button keypad legends for ASCII output*
Lookup Key,["F","7","4","1","0","8","5","2","E","9","6","3","D","C","B","A"," "],Key

If your particular keypad does not match up with the values displayed, simply re-arrange the values within the braces of the LOOKUP command.

To determine which keys are which, comment the LOOKUP command and place a SEROUT or DEBUG command just after it. This will display the value held in the variable **KEY**. Whichever value is returned for the 0 button will be the first value within the braces of the LOOKUP command.

Serial keypad controller

The use of a keypad is often essential but it still takes up precious pins on the microcontroller that could have other functions, therefore, the logical solution is to send out the data from the keypad serially. This means that only one or two pins are used up on the PIC. Figure 2.4 shows the circuit for such a controller. The keypad controller sends out async serial data at either T1200 baud or T9600 baud.

The three LINKS connected to PortA and PortB; configure several different properties within the controller code.

LINK1 configures the serial output baud rate. When connected, 9600 is transmitted, and when left unconnected, 1200 baud is transmitted. The lower baud has been chosen so that a serial IR transmitter or a radio transmitter may be connected.

LINK2 selects the output type. When connected, ASCII values are transmitted, where the value sent reflects the ASCII value of the key (*button A will send the value 65*). When unconnected, numeric values are transmitted, where the actual key values are sent (*button 3 will send the value 3*).

LINK3 selects the number of buttons on the particular keypad used. Connected will interface to a 16-button keypad, and unconnected will interface with a 12-button type.

The **STROBE** pin (PortB.6), will be high 50ms before the serial data is transmitted, and low just after the end of transmission. This may be used as an indicator or as a data validation line to the receiving PIC that a key has been pressed and serial data is on its way. By using the NAP command within the waiting loop of the main program, the controllers current consumption is only 0.4mA.

Experimenting with the PicBasic Pro Compiler

The program, **SERKEY.BAS** is based around the keypad scanning subroutine **INKEYS**, this is a modified version of the standard subroutines explained in the previous experiments. The main loop of the program examines the pins where the links are attached, and places their value into three flags, **BUTTONS**, **NUMERIC**, and **BAUDRATE**, these now contain 1 or 0 according to whether the pins are connected or not. The internal pullups and R2 ensure that when a link is not connected the pin will always remain high.

The link flags are used to construct the different configurations by simple *if-then* commands located at places within the code that require a different product for the specified link connection or disconnection.

The format for the serial data transmitted is : -

> *Sync byte "@" , Key Value , Debounce flag*

This is sent as True polarity 9600 or 1200 baud.

Low current consumption is achieved by continuously using the NAP command when no key is pressed. This means that the PIC is off more than it is on. The NAP command places the PIC into low power mode for 18ms, which means there is an 18ms delay before the keypress is responded to, however, this is not noticed as the keypad is not a time critical component.

Again:
```
    Gosub Inkeys                  ' Go and scan the keypad
    If Key=128 or Key=32 then     ' If no key pressed do the following: -
    Nap 0                         ' Go into low power mode for 18ms
    Goto Again                    ' And look again when woken up.
    Endif
```

The circuit shows a 16-button keypad connected, however, if a 12-button type is used instead, connections are as figure 2.2.

Link 1
Connected...9600 baud
Open............1200 baud

Link 2
Connected...ASCII output
Open............Numeric output

Link 3
Connected...16-button keypad
Open............12-button keypad

+5 Volts

R1
4.7k

R2
47k

R3
220k

14
VDD   RB7   13   Serial Out
4
MCLR   RB6   12   Strobe
       RB5   11
       RB4   10
4mHz   RB3   9
Crystal RB2 8
16   RB1   7
OSC1   RB0   6

PIC16F84

       RA4   3
14   RA3   2
OSC2   RA2   1
       RA1   18
       RA0   17

VSS   5

C1
10uf

C2
0.1uf

C3
22pf

C4
22pf

Link 3
Link 2
Link 1

R4-R7
470

A   B   C   D
3   6   9   E
2   5   8   0
1   4   7   F

0v
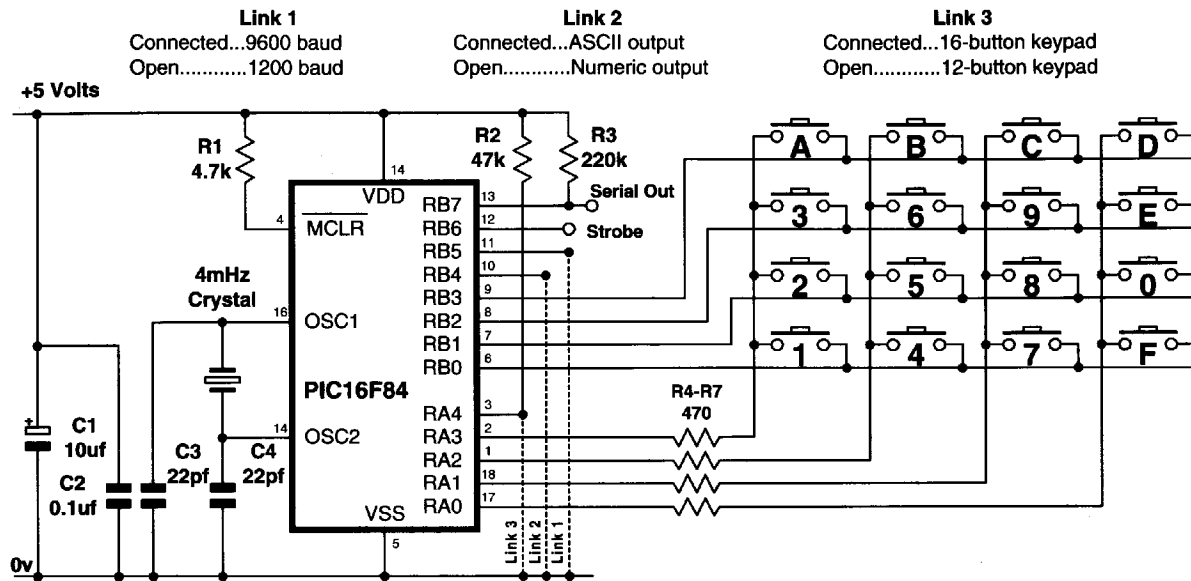
Figure 2.4. Serial keypad controller circuit.

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Program - KEYIN.BAS

Receiving data from the serial keypad controller

The program **KEYIN.BAS** demonstrates how to receive the serial data from the serial keypad controller and display the results on a serial LCD display, connected to PortA.1, configured for N9600 baud. The subroutine **KEYIN** continually looks for the sync byte "@" and when found, reads in the next two bytes which contain the value of the key pressed, and the debounce flag. It then returns with these values in the variables **KEY and DEBOUNCE**: -

```
       Key       Var      Byte       'Button pressed variable
       Debounce  Var      Byte       'Debounce Flag
Keyin:
       Serin PortA.0,T9600,Key       'Look for the sync byte
       If Key<>"@" then goto Keyin   'Look again if not found
       Serin PortA.0,T9600,Key,Debounce
       Return
```

Alternatively, the SERIN2 or DEBUGIN commands may be used. These have the ability to wait for a specific sequence of characters before receiving the Key and Debounce data, and not surprisingly, this operand is called WAIT. The subroutine above can be changed to: -

```
       Key       Var      Byte       'Button pressed variable
       Debounce  Var      Byte       'Debounce Flag
       B9600     Con      84         'T9600 baud
Keyin:
       Serin2 PortA.0 , B9600 , [ wait ( "@" ) , Key , Debounce]
       Return
```

Timeout values may be added, so that if a key is not pressed within a certain time frame the subroutine is exited. The flexibility of the compiler's serial data commands are too numerous to explain, the PBP manual should never be far away.

Alternatively the STROBE pin may be connected and periodically examined, if it is high then the keypad is transmitting, and low means the keypad is untouched.

Experimenting with the PicBasic Pro Compiler

Assembler coded, Keypad decoder

The assembler coded, keypad decoder is in the form of an include file **ASM_KEY.INC**, its use is essentially the same as the BASIC coded versions, except there is no debounce flag returned i.e. **DEBOUNCE**. There are however, two new Defines added for the keypad, the first, informs the subroutine whether a 12 or 16-button keypad is being used, these are: -

> *Define   KEYPAD_BUTTONS   12   'Use a 12-button keypad*
> or
> *Define   KEYPAD_BUTTONS   16   'Use a 16-button keypad*

The wiring of the keypads are shown in figures 4.2 and 4.3.

The second Define informs the subroutine, whether to return the variable **KEY** with the ASCII value of the key pressed or the numeric value: -

> *Define   KEYPAD_RETURN   0   'Return the numeric value*
> or
> *Define   KEYPAD_RETURN   1   'Return the ASCII value*

If the NUMERIC value is chosen, the variable, **KEY** will be returned from the subroutine holding the numeric equivalent of the legends printed on the keypad buttons (*0 will return a value of 0, A will return a value of 10 etc.*), and 128 if no button pressed. If the ASCII value is chosen, **KEY** will return holding the ASCII equivalent of the legends printed on the keypad buttons (*0 will return a value of 48, A will return a value of 65 etc.*), and 32 (*space*) if no button pressed.

If no Defines are added to your program, the default settings are, 12-button keypad, returning the NUMERIC values.

The ports on which the keypad is connected, are automatically configured for the correct input/output configuration each time a call is made to the subroutine **INKEYS**. And the variable, **KEY** is already pre-declared within the include file. Make sure that the include file is placed at the beginning of your program, in order to minimize the risk of page boundary conflicts. The program **ASM_KEY.BAS** is a demonstration for using the assembler coded keypad decoder.

INKEYS, pseudo command

Within the include files **INKEYS12.INC** and **INKEYS16.INC**, a macro has been defined which allows the use of a pseudo command called **INKEYS**. Instead of calling the subroutine **INKEYS** and having the value of the key pressed returned in **KEY**, and the debounce flag in **DEBOUNCE**, we can place these values into any variable we choose. The use of the **INKEYS** command is: -

Variable1	*Var*	*Byte*	*BANK0*	*SYSTEM*
Variable2	*Var*	*Byte*	*BANK0*	*SYSTEM*

@ INKEYS Variable1 , Variable2

Variable1 will hold the key pressed and *Variable2* will hold the debounce flag. There are three things to remember when using the pseudo command. Always place the @ symbol at the beginning of the line, also any variables used within the command should be declared as BANK0 variables.

Also, don't forget to declare the variables as SYSTEM types, or an underscore must precede them.

Both variables are optional, if *Variable2* is not used the debounce flag will be placed into **DEBOUNCE**. And if *Variable1* is not used the key value will be placed into **KEY**.

Section-3

Experimenting with Serial Eeproms

Giving the PIC a memory.
Microwire Interface principals.
SPI Interface principals.
I^2C Interface principals.
I^2C eeprom interfacing principals
Interfacing to the 24C32, I^2C serial eeprom.
Interfacing to the 24C32 using the MSSP module.
Interfacing to the 93C66, Microwire serial eeprom.
Interfacing to the 25LC640, SPI serial eeprom.

Giving the PIC a memory.

If you have a project that requires long-term memory storage (*up to 200 years*) that will not fit into the PIC's internal eeprom, an external serial eeprom (*SEEPROM*) may be the answer. These small and inexpensive devices are easily interfaced to any of the PIC range. This section is a guide to choosing and using seeproms. We will compare the three major interface types: Microwire, SPI, and I²C, also the advantages and disadvantages of using each type.

All serial eeproms use a synchronous serial interface (*SSI*), this means that both the eeprom and the microcontroller use a common clock and a clock transition signal to indicate when to send or read each bit. Some synchronous serial devices require minimum clock frequencies, the clock for seeproms can be as slow as required, or as fast as a few mHz's. The microcontroller can strobe the clock at its convenience, up to the maximum speed of the device.

Serial eeproms normally have just eight pins, power, ground, one or two data/address lines, and a clock input, plus up to three other control signals. However, unlike parallel eeproms, which require extra pins to be added as the number of address and data lines grow, a seeprom's physical size does not have to increase with its memory capacity.

Eeproms use CMOS technology; therefore, they consume minute amounts of power, with currents as low as a few *uA* in standby mode and a *mA* or so when active.

Depending on the device, the maximum clock speed for accessing serial eeproms may be over 2mHz. However, because it takes eight clock cycles to transfer a byte, and the master also needs to send instructions and addresses, the maximum rate of data transfer is usually no more than 4ms per byte. Write operations actually take much longer, because the eeprom needs several milliseconds to program a byte into its memory array. During this time, the PIC cannot read or write to the eeprom.

With continued use, eeproms eventually lose their ability to store data, so they are not suited for applications where the data changes constantly.

Experimenting with the PicBasic Pro Compiler

Most are rated for between 1 million and 10 million erase/writes, which is OK for data that changes occasionally, or even every few minutes.

It's not only eeproms that use a serial interface, other devices with synchronous serial interfaces include, A/D, D/A converters, clocks, and display interfaces etc, all of these devices are used extensively in this book. Therefore, this section will give an insight on how other devices using a serial interface communicate with the PIC. Multiple devices can connect to one set of data lines, with each chip having its own Chip-Select line (*CS*) or firmware address, this effectively means that if two devices are connected then the second device may only require one extra pin.

After you have decided to use a serial eeprom, the next step is to select one of the three serial protocols. In conventional assembler programming, the 3-wire devices won easily because of the simplicity of their interface. However, with the compiler's I^{2}C and Shift commands, interfacing to any of the devices is greatly simplified.

To see how the different interfaces compare, we will look at an eeprom of each type.

Table 3.1 summarizes the major features of each type used.

Interface Type	Microwire	SPI	I^{2}C
Device	93C66	25LC640	24C32
Memory capacity	4Kbits	64Kbits	32Kbits
Number of interface pins	4 or 3	4 or 3	2
Data width (bits)	8 or 16	8	8 or 16
Maximum clock speed	2mHz	2mHz	400kHz
Write (busy) time	10ms	5ms	10ms
Max No. of bytes programmed in one operation	2	32	16
Writes bit on (clock state)	Rising edge	Rising edge	Low level
Reads bit on (clock state)	Rising edge	Falling edge	Low level
Chip select method	Hardware	Hardware	Software

Table 3.1. Comparison of SPI, Microwire, and I^{2}C eeproms.

Microwire interface principals

Atmel's 93C66 is an 8-pin, 4Kbit serial eeprom with a Microwire interface. It has two data pins, data in (*DI*) and data out (*DO*), a clock input (*SK*), and a chip-select (*CS*). Additional inputs are for memory configuration, (*ORG*), which determines whether data format is 8 or 16-bits, and program enable (*PE*), which must be high to program the chip. The memory is organised as 256 words of 16-bits each when the ORG pin is attached to Vcc, and 512 words of 8-bits each when ORG is connected to ground.

Although it is sometimes called a 3-wire interface, a complete connection actually requires four signal lines. However, use of the PIC's ability to rapidly switch states from input to output means that the *data in* and *data out* pins may be connected to the same pin on the PIC.

The eeprom understands seven instructions, these are, ERASE/WRITE ENABLE and DISABLE, WRITE, READ, ERASE, ERASE ALL (*sets all bits to 1*), and WRITE ALL (*writes one byte value to all locations*). Each instruction must begin with a Start condition, which occurs when CS and DI are both high on the clocks rising edge. DI is brought high naturally when an instruction is written, because all of the instructions begin with one. The PIC must bring CS low after each instruction, except for a sequential read. When CS is brought high, the eeprom is placed into standby, ignoring all instructions until it detects a new start condition.

To write to the eeprom, the PIC must first send an ERASE/WRITE ENABLE instruction to DI, followed by a WRITE instruction, the write bits are written on the clocks falling edge, and the eeprom latches each bit on the next rising edge. After sending the final data bit in a programming sequence, the PIC must bring CS low before the next rising edge of the clock (*SK*). This causes the eeprom to begin its internal programming cycle. The programming is self-timed which means that it requires no clock cycles. If CS returns high before the programming cycle is complete, D0 will indicate Ready/Busy status. CS must then go low again to complete the write operation.

The PIC needs to send the Erase/Write Enable instruction just once per programming session. The device remains write-enabled until it receives an Erase/Write Disable instruction or power is removed.

To read from the eeprom, the PIC sends a READ instruction to DI, followed by the address to read. When the eeprom receives the final address bit, it writes a *dummy zero* to D0, then writes the requested data on the clocks rising edges.

If CS remains high after a read operation, additional clock transitions will cause the chip to continue to output data at sequential addresses. If CS goes low, the next read operation must begin with the read instruction and an address.

SPI Interface principals

SPI is very similar to Microwire, although polarities and other details vary. As with Microwire, SPI eeproms write bits on the clock's rising edge, however, unlike Microwire, they latch input bits on the falling edge. The polarity of CS (*active low*) is also opposite from the Microwire convention

Microchip's 25LC640 is a 64Kbit eeprom with an SPI interface, organised as 8192 words x 8-bits. In addition to the four interface lines, the chip has two other inputs. WP (*write protect*), which must be high to program the device. Moreover, for interfaces with multiple slaves, the HOLD input enables the PIC to pause in the middle of a transfer in order to do something more urgent on the SPI bus. The eeprom ignores all activity on the SPI bus until HOLD returns high, then both devices carry on where they left off.

The eeprom understands six instructions, these are, SET AND RESET THE WRITE ENABLE LATCH, READ AND WRITE TO THE STATUS REGISTER, and READ AND WRITE TO THE MEMORY ARRAY. The eeprom has several levels of write protection, which may be used to virtually guarantee that there will be no unintentional writes to the device. If WP is low, no changes to the data are allowed. If WP is high, two non-volatile bits in the chip's *status register* can block writes to all, or a portion of the device. Finally, if WP is high, before you can write to the status register or the portion of memory enabled in the status register, the eeprom must receive a Set Write Enable Latch instruction.

Experimenting with the PicBasic Pro Compiler

To write to the eeprom, the PIC sends a SET WRITE ENABLE LATCH instruction to SI, followed by a WRITE instruction, then the highbyte and lowbyte of the address are sent, then the data to write. The PIC may send up to four data bytes for sequential addresses in one operation. After clocking the final data bit with SCK low, CS must go high to begin programming the byte into the eeprom.

While the eeprom is programming the data, the PIC can read the eeprom's status register. When bit-0 of the status register is 0, the eeprom has finished programming, and the next write operation may begin. The chip is write-protected after each programming operation; therefore, each write must begin with a SET WRITE ENABLE LATCH instruction.

To read the eeprom, the PIC sends a READ instruction followed by the highbyte and the lowbyte of the address. The eeprom responds with the data bits in sequence on SO. As with Microwire, additional clocks will cause the eeprom to send additional data bytes in sequence.

I²C Interface principals

I²C is a synchronous serial bus, developed by Philips to allow communication between different peripherals. Many devices such as eeproms, ADCs, LCD drivers, DACs, etc support the I²C bus protocol. These devices communicate through a 2-wire bus, with data transfer rates of 100Kbit/s, 400Kbit/s, and even 1Mbit/s. The number of devices on the bus is limited by the maximum bus capacitance of 400pF.

Most devices are used as slaves while microcontrollers are typically masters. I²C also supports multi-mastering, which means more than one device is allowed to control the bus. I²C has collision detection and arbitration to maintain data integrity. The two lines used for I²C interfacing are, Serial Data Address Line (*SDA*) and Serial Clock Line (*SCL*). Both of these are bi-directional.

I²C: Protocol

I²C is a multi-master/slave protocol. All devices connected to the bus must have an open-collector or open-drain output. A transaction begins when the bus is free (*i.e. both SCL and SDA are high*), a master may initiate a transfer by generating a START condition. Then the master sends an address byte that contains the slave address and transfer direction. The addressed slave device must then acknowledge the master. If the transfer direction is from master to slave, the master becomes the transmitter and writes to the bus. While the slave becomes the receiver and reads the data and acknowledges the transmitter, and vice-versa. When the transfer is complete, the master sends a STOP condition and the bus becomes free. In both transfer directions; the master generates the clock SCL and the START/STOP conditions.
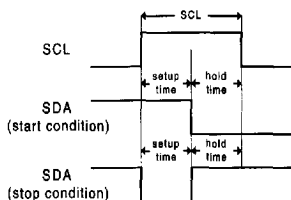
Figure 3.1. I²C START/STOP conditions.

The START condition is generated by a high to low transition on the SDA line during the High period of the SCL line, as shown in figure 3.1.

A stop condition is generated by a low to high transition on the SDA line during the High period of the SCL line, also shown in figure 3.1.

The number of bytes transferred per START/STOP frame is unrestricted.

Data bytes must be 8-bits long with the most significant bit (*MSB*) first. Each valid data bit sent to the SDA line must remain high for '1' or low for '0' during the high period of the SCL, otherwise any transition in the SDA line while SCL is high will be read as a START/STOP condition. Thus, transitions can only be made during the low period of SCL. An acknowledge bit must follow each byte. After the last bit of the byte is sent, an ACK clock (*acknowledgement clock*) is generated by the master (9th *clock*). An ACK (*acknowledge bit, low*) must be sent by the receiver and remain low during the high period of the ACK clock.

If the slave (*receiver*) doesn't return an ACK (*e.g. an error, or is unable to receive the data*), then the slave device must leave the SDA line high (*NACK*). The master will abort the transfer by generating a STOP condition. If the slave does return an ACK, but sometime later it is unable to receive any more data. Then the slave must generate a NACK (*not acknowledge, high*) on the first byte to follow. The slave will then need to keep the SDA line high for the master to generate a stop condition. If the receiver is the master and the transfer is ending. Then the master needs to send a NACK after the last byte is sent. The slave (*now a transmitter*) must release the SDA line to high, this allow the master to generate a START/STOP condition.

At the beginning of each transfer, the master generates the START condition then sends a slave address. The standard slave address is 7-bits (*sometimes 10-bits*) followed by a direction or R/W bit (8th *bit*) as shown in figures 4.2 and 4.3. When the direction bit is a WRITE (*zero*), the addressed slave device becomes the receiver and the master becomes the transmitter. When the direction bit is a READ (*one*), the addressed slave device becomes the transmitter and the master becomes the receiver.

I²C Serial eeprom interface principals

Microchip's 24C32 is a 32Kbit serial eeprom using an I²C interface, the memory organisation is 4096 words x 8-bits, or 2048 words x 16-bits. The slave address assigned to this device by the manufacturer is 1010XXX, where X = Don't Care. The eeprom supports several transfer modes such as, BYTE WRITE, PAGE WRITE, CURRENT ADDRESS READ, RANDOM READ, and SEQUENTIAL READ.

To perform a Byte Write, the master generates a START condition and sends the slave address with the direction bit set to WRITE (*zero*) as in figure 3.2. When the slave device matches the address, it sends an ACK to the master during the ninth clock cycle. The next byte sent to the eeprom will be the word address that moves its internal address pointer. Then the data sent by the master will be written to the memory location pointed to by this address. Finally, the master generates a STOP condition, which will signal the eeprom to initiate the internal write cycle. At this time the eeprom will not generate any acknowledge signals until the transaction is complete.

A Page Write is similar to a Byte Write, except the master may transmit up to eight bytes before generating a stop condition. Each byte sent to the device will increment the address pointer for the next byte transaction. The eeprom stores the data in an eight-byte buffer, which is then written to memory after the device has received a stop condition from the master, as in figure 3.2.
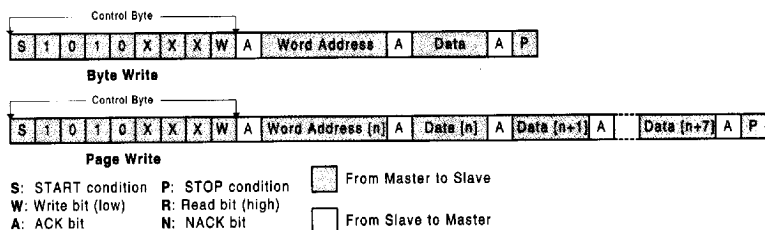
Figure 3.2. Write transfers.

Read operations are initiated the same way as a write operation except the direction bit is set to READ (one). The eeprom keeps the address pointer from the last byte accessed incremented by one. In a Current Address Read transaction, the eeprom acknowledges the master after receiving the slave address and transmits the data byte pointed by its internal address pointer, see figure 3.3. The pointer is incremented by one for the next transaction. Sequential Reads behave the same way as a Current Address Read transaction except data is continually transmitted by the slave device until the master generates a STOP condition see figure 3.3.

For Random Read, the master generates a START condition then sends the slave address with the direction bit set to WRITE (*zero*). Then the next byte sent is the word address to be accessed. This operation will change the eeprom's internal address pointer. Then without generating a STOP condition, a Current Address Read or Sequential Read transaction will follow.

Notice that the Current Address Read and Sequential Read transaction generate another START condition, as shown in figure 3.3.
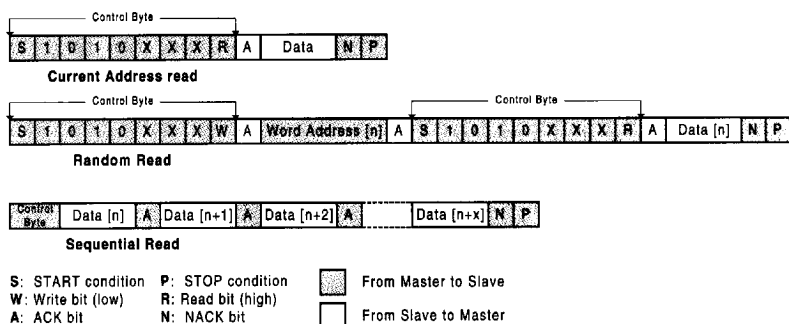
Figure 3.3. Read transfers.

Interfacing to the 24C32 I^{2}C eeprom

Now that we know the principals behind serial eeprom interfacing, we can develop a pair of subroutines that will automate reading and writing to them. The Microchip 24C32 is an I^{2}C device that can store 4096 bytes of data. Figure 3.4 shows the eeproms connections to the PIC.
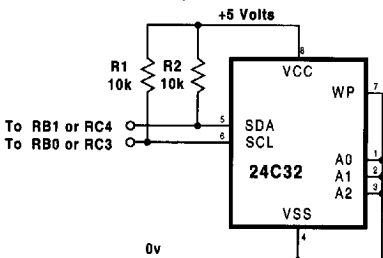
Figure 3.4. 24C32 eeprom connections.

Writing to the eeprom

The subroutine **EWRITE** is used for this purpose. It expects two variables to be pre-loaded before its use. The first is the address within the eeprom where the data is to be stored, this is held in the 16-bit variable **ADDR**, the second is the data to write to the eeprom, this is held in the variable **E_BYTEOUT**.

Within the **EWRITE** subroutine, the I2CWRITE command sends three lots of data to the I^{2}C bus; firstly the *slave* address is sent, (*this must always start with %1010, which is the serial eeprom device identifier*). If there is more than one eeprom on the I^{2}C bus then the next three bits will reflect the pattern on the A2, A1 and A0 pins. However, for this demonstration we are only using one device, therefore, they are cleared. So the slave address is %10100000, the I2CWRITE command will automatically set the read/write bit. The next lot of data sent is the 16-bit memory address, and finally the BYTE or WORD sized value to be placed at the address location is sent. A delay of 10ms is required after the write is performed; this allows the eeprom time to allocate the data into its memory array: -

EWrite:
*   I2CWRITE SDA,SCL,%10100000,Addr,[E_ByteOut] 'Write the byte*
*   Pause 10   ' Delay 10ms after each write*
*   Return*

If the variable **E_BYTEOUT** is declared as a BYTE, then 8-bits will be written. If the variable is declared as a WORD then 16-bits will be written

Reading from the eeprom

The subroutine **EREAD** is used for this purpose. It reads 8 or 16-bits from the eeprom. Before the subroutine is called, the address of interest must be loaded into the variable **ADDR**. Upon returning from the subroutine, the data from the specified address location is held in the variable **E_BYTEIN**.

The **EREAD** subroutine uses the I2CREAD command. The slave address (*as in EWRITE*) and the 16-bit memory address are sent. Then the data is read into the assigned variable. Its use is: -

```
ADDR = 1024              ' Point to location 1024 within the eeprom
Gosub Eread              ' Read the data from the specified location
' The variable E_BYTEIN now holds the byte of data

ERead:
    I2CREAD SDA,SCL,%10100000,Addr,[E_ByteIn]   ' Read the byte
    Return
```

Unfortunately, the compiler's I2CREAD and I2CWRITE commands do not use the acknowledge returns from the bus. Therefore, this method cannot be used to verify whether a successful write has been performed.

One way to get round this, is to read the data back from the same address that it has just been written to, and compare the result. For example.

```
Write:
    ADDR = 1024              ' Point to location 1024 within the eeprom
    E_BYTEOUT = 128          ' Place the value 128 in the address
    Gosub EWrite             ' Write the byte to the specified address
    Gosub Eread              ' Read the data from the same address
    If E_Bytein <> E_Byteout then goto WRITE    ' Compare them
```

This compares the variable **E_BYTEIN** with the variable **E_BYTEOUT**, and if they are not the same then the WRITE process is carried out again. This will slow down the writing process slightly, but a successful write is guaranteed. Unless the eeprom has come to the end of its life.

The include file **24XXX.INC,** contains the two subroutines, **EREAD**, and **EWRITE**. This should be loaded near the beginning of the main program, just after declaring the SCL and SDA pin assignments: -

```
SCL       VAR   PortB.0      ' Assign PortB.0 to SCL
SDA       VAR   PortB.1      ' Assign PortB.1 to SDA
Include "24XXX.INC"          ' Load the read/write subroutines
```

The variable, **ADDR** is already pre-declared within the include file. The variables **E_BYTEIN** and **E_BYTEOUT** need to be declared within the main program. Depending on how these variables are declared dictates if an 8 or 16-bit read/write is performed. For example.

Declaring **E_BYTEIN** as a WORD type will enable 16-bit reads, and declaring it as a BYTE type will enable 8-bit reads. The same applies for **E_BYTEOUT**.

This is possible due to the I2C command's ability to automatically detecting if a variable is a byte or a word, thus transferring 8 or 16-bits.

NOTE. The subroutines may be used for the 24C16, 24C32, 24C64, and 24C65 eeproms. They may work on other 24xxx series eeproms, but have not been tested.

Experimenting with the PicBasic Pro Compiler

Interfacing to the 24C32 eeprom, using the MSSP module

The new mid-range PICs, 16F872, 873, 874, 876, and 877 all have a master synchronous serial port module (*MSSP*), which may be configured as an SPI master/slave or I²C master/slave. We are intending to read and write to a 24C32 eeprom, therefore, we will discuss how to configure, and use the MSSP as an I²C master device. There are several registers and bits that need to be manipulated for master mode to be configured. We will look at each register in turn.

Firstly, the SDA (*PORTC.4*) and SCL (*PORTC.3*) pins need to be made inputs.

The CKE bit (*SSPSTAT.6*) needs to be cleared. This will configure the MSSP module to comply with normal I²C specifications.

The SMP bit (*SSPSTAT.7*) needs to be set. This disables the slew rate control, (*which is not needed for a 100kHz bus speed*).

The first four bits of SSPCON are given the values of %1000. This configures the MSSP as an I²C master.

The baud rate generator register (*SSPADD*) is next loaded with the bus speed required. The formula for this is: -

$$SSPADD\ value = (OSC\ /(BUS\ SPEED\ *\ 4))\ -1$$

In this experiment, we are going to use a bus speed of 100kHz, and an oscillator of 20mHz. Therefore, the value placed in SPPADD is 49. This is automatically calculated for us in the programs.

Lastly, the MSSP module has to be enabled. This is accomplished by setting the SSPEN bit (*SSPCON.5*).

Now that we have the MSSP configured, the next thing to do is write a pair of subroutines that manipulate the I²C bus for reading and writing to the eeprom.

A typical sequence for WRITING to a serial eeprom is: -

Send START: The start condition enable bit, SEN (*SSPCON2.0*) must be set. After the start command has been sent, the SEN bit will be cleared. If a bus collision occurred, the interrupt flag BCLIF (*PIR2.3*) will be set.

Send slave address: The slave address is loaded into the SSPBUF register with the R/W bit (*D0*) cleared. The code must check the RW flag (*SSPSTAT.2*) to see whether the PIC has finished transmitting its 8-bits. Upon completing the transmission, the buffer full flag, BF (*SSPSTAT.0*) will be cleared. The eeprom now acknowledges the byte, and this is placed in the acknowledge status flag ACKSTAT (*SSPCON2.6*). If an acknowledge was received, this flag will be cleared, if not then the flag will be set.

Send high byte (MSB) of memory address: The same sequence as above, but the highbyte of the memory address is sent instead of the slave address.

Send low byte (LSB) of memory address: The same sequence as send slave address, but the lowbyte of the memory address is sent instead of the slave address.

Send the byte to place into the eeprom: The same sequence as send slave address, but with the byte to place into the eeprom sent instead of the slave address.

Send STOP: The stop sequence enable bit, PEN (*SSPCON2.2*) must be set. After the stop command has been sent, the PEN bit will be cleared, and the interrupt flag, SSPIF (*PIR1.3*) is set.

Experimenting with the PicBasic Pro Compiler

A typical sequence for READING from a serial eeprom is: -

Send START: The start condition enable bit, SEN (*SSPCON2.0*) must be set. After the start command has been sent, the SEN bit will be cleared. If a bus collision occurred, the interrupt flag BCLIF (*PIR2.3*) will be set.

Send slave address for write: The slave address is loaded into the SSPBUF register with the R/W bit (*D0*) cleared. The code must check the RW flag (*SSPSTAT.2*) to see whether the PIC has finished transmitting its 8-bits. Upon completing the transmission, the buffer full flag, BF (*SSPSTAT.0*) will be cleared. The eeprom now acknowledges the byte, and this is placed in the acknowledge status flag ACKSTAT (*SSPCON2.6*). If an acknowledge was received, this flag will be cleared, if not then the flag will be set.

Send high byte (MSB) of memory address: The same sequence as above, but the highbyte of the memory address is sent instead of the slave address.

Send low byte (LSB) of memory address: The same sequence as send slave address for write, but the lowbyte of the memory address is sent instead of the slave address.

Send RESTART: The repeated start condition enable bit, RSEN (*SSPCON2.1*) must be set. After the restart condition has been transmitted, the RSEN bit is cleared, and the SSPIF flag is set.

Send slave address for read: The slave address is loaded into the SSPBUF register with the R/W bit (*D0*) set. And the same sequence of events occur as for the first slave address transmission.

Send ENABLE RECEIVE: The receive enable bit, RCEN (*SSPCON2.3*) must be set. This has the effect of making the slave (*eeprom*) a temporary master. After receiving the 8-bits from the eeprom, the RCEN bit is cleared and the buffer-full flag (*BF*) is set. The contents of the buffer (*SSPBUF*) is then read, this automatically clears the buffer-full flag (*BF*).

Send NACK: The slave (*eeprom*) is still a temporary master, therefore, to notify it to be a slave again it must be sent a NACK (*not acknowledge*) command (*this releases the SDA line*). Firstly, the acknowledge data bit, ACKDT (*SSPCON2.5*) and the acknowledge sequence enable bit, ACKEN (*SSPCON2.4*) must be set. The ACKEN bit is automatically cleared when the NACK command is over.

Send STOP: Finally, the stop sequence enable bit, PEN (*SSPCON2.2*) must be set. After the stop command has been sent, the PEN bit will be cleared, and the interrupt flag, SSPIF (*PIR1.3*) is set.

The program **SSP_24XX.BAS**, reads and writes to a 24C32 eeprom. The first eleven bytes of the eeprom are written to, and then read back, this is displayed on a serial LCD connected to PortA.0. The program breaks up the above procedures into a set of subroutines, send_start, send_stop, send nack etc, and then uses two main subroutines for writing and reading to and from the eeprom.

The writing subroutine, **EWRITE**, expects two variables to be pre-loaded before it is called. The variable **ADDR**, holds the memory address within the eeprom, and **E_BYTEOUT**, hold the byte to place into the eeprom.

The reading subroutine, **EREAD**, must have the **ADDR** variable loaded before it is called. Upon returning, the byte read from the eeprom is held in the variable **E_BYTEIN**.

One thing that you must have noticed (*I know I did*) is that for a hardware solution there sure is a lot of code needed. To minimize the code overhead, assembler subroutines must be used. That is the purpose of the include file **SSP_24XX.INC**, this has exactly the same layout as the BASIC program, except it is a lot smaller. The two subroutines, **EREAD** and **EWRITE** are again used, with one exception. The slave address must be pre-loaded before the subroutines are called, this is held in the variable, **SLAVE_ADDR**. As the I²C bus can support upto eight serial eeproms, the value placed within this variable may be between 0..7.

The MSSP module is automatically configured when the include file is loaded, also the variables, **ADDR, E_BYTEIN, E_BYTEOUT**, and **SLAVE_ADDR** are pre-declared.

Experimenting with the PicBasic Pro Compiler

Using the pseudo commands EREAD and EWRITE

An alternative method for reading and writing to the eeprom is the use of two new *pseudo commands*. These are also named **EREAD** and **EWRITE**, and are ready for use when the include file **SSP_24XX.INC** is loaded. Their syntax and use are explained below.

The eeprom writing command is called **EWRITE**, its syntax is: -

EWRITE   slave address , memory address , byte written to the eeprom

The slave address must be a constant between 0..7. The memory address may be any WORD variable. The byte written may be any BYTE variable. Its use is: -

```
Address    Var  WORD       SYSTEM   ' Eeprom memory address
Byte_Sent  Var  BYTE       SYSTEM   ' Byte placed into eeprom

      Address = 1000                ' Point to address 1000
      Byte_Sent = 128               ' Write 128 into the eeprom
@     EWRITE  0 , Address , Byte_Sent ' Write the byte
```

The eeprom reading command is called **EREAD**, its syntax is: -

EREAD   slave address , memory address , byte read from the eeprom

The slave address must be a constant between 0..7. The memory address may be any WORD variable. The byte read may be any BYTE variable. Its use is: -

```
Address    Var  WORD       SYSTEM   ' Eeprom memory address
Byte_Rec   Var  BYTE       SYSTEM   ' Byte read from eeprom

      Address = 1000                ' Point to address 1000
@     EREAD  0 , Address , Byte_rec  ' Read the byte
' The variable Byte_Rec now holds the value read from the eeprom
```

The @ symbol must always precede the pseudo command, as it is essentially an assembler macro.

Experimenting with the PicBasic Pro Compiler

Interfacing to the 93C66 Microwire eeprom

Reading and writing to the Atmel 93C66 eeprom is slightly more involved than its I^{2}C counterpart, because it uses instructions in the form of *op-codes* to inform the eeprom as to what function it should perform. Also, the exact amount of bits per instruction must be sent, otherwise the eeprom will ignore the instruction and return to standby.

A brief description of the seven instructions is shown in table 3.2.

Instruction	Start-bit	Opcode	Address	Data In	Data Out	Req Clk cycles
READ	1	10	A8 - A0	---	D7 – D0	20
EWEN	1	00	11XXXXXXX	---	High - Z	12
ERASE	1	11	A8 – A0	---	(RDY/BSY)	12
ERAL	1	00	10XXXXXXX	---	(RDY/BSY)	12
WRITE	1	01	A8 – A0	D7 – D0	(RDY/BSY)	20
WRAL	1	00	01XXXXXXX	D7 – D0	(RDY/BSY)	20
EWDS	1	00	00XXXXXXX	---	High - Z	12

Table 3.2. Instruction set for 93C66: ORG = 0 (x8 organization).

The program **93C66.BAS**, writes the string of characters "HELLO WORLD" to the first eleven locations within the eeprom, then reads them back and displays them on a serial LCD connected to PortA.0. Figure 3.5 shows the eeprom's connections to the PIC.

Four subroutines are used within the main program, these are: -

EWRITE_EN, enables the eeprom for writing by shifting out the op-code %10011, followed by seven *dummy bits*. No variables need be set.

EWRITE_DS, disables the eeprom for writing by shifting out the op-code %10000, followed by seven *dummy bits*. No variables need be set.

EWRITE, brings the CS line high (*enabling the eeprom*), then writes a byte to the eeprom by first shifting out the op-code %1010, followed by the memory address, held in the variable **ADDR**, then the byte to send to the eeprom is shifted out, which is held in the variable **E_BYTEOUT**. The CS line is then pulled back low (*disabling the eeprom*), and a delay of 10ms is executed, this allows the byte written to the eeprom to be allocated within its memory array: -

Ewrite:
    High CS   *' Enable the eeprom*
' Send WRITE command, ADDRESS and DATA
    Shiftout DI,SK,MSBFIRST,[EWR\4,Addr,E_Byteout]
    Low CS   *' Disable the eeprom*
    Pause 10   *' Allow the eeprom to allocate the byte*
    Return

EREAD, brings the CS line high (*enabling the eeprom*), then reads a byte from the eeprom by first shifting out the op-code %1100, followed by the memory address, held in the variable **ADDR**, it then shifts in the byte from the eeprom to the variable **E_BYTEIN**. The CS line is then pulled back low (*disabling the eeprom*): -

Eread:
    High CS   *' Enable the eeprom*
' Send READ command and ADDRESS
    Shiftout DI,SK,MSBFIRST,[ERD\4,Addr]
' Read the data into E_BYTEIN
    Shiftin DO,SK,MSBPOST,[E_Bytein]
    Low CS   *' Disable the eeprom*
    Return

Care must be taken when choosing a Microwire device. For example, Microchip has two versions of the 93C66, one has the denomination 'A' after the name, the other has a 'B'. The A type is permanently configured as 512 words x 8-bits, while the B type is configured as 256 words x 16-bits. In both types, the ORG pin is not implemented. The same applies for their 93LC66 versions.

Figure 3.5. 93C66 eeprom connections.

R1 allows the data-in and the data-out lines to share the same PIC pin. R2 is precautionary only, it ensures that when the circuit is first powered up the chip is disabled. This may be omitted if required.

Experimenting with the PicBasic Pro Compiler

Interfacing to the 25LC640 SPI eeprom

Microchip's 25LC640 is a 64Kbit serial eeprom, which is organised as 8192 words x 8-bits, and uses an SPI interface. Reading and writing to the 25LC640 has similarities to Microwire interfacing, although it is somewhat easier to implement (*this could be one possible reason why the Microwire interface is becoming unpopular with designers*). SPI eeproms are certainly easier to implement with low level programming (*assembler*), than their I^2C counterparts.

SPI eeproms still use instructions to perform specific functions (*read, write etc*), however, it is not as stringent with its protocol as Microwire. A brief description of the six instructions is shown in table 3.3.

Instruction	Op-code	Instruction Description
READ	0000 0011	Read memory from memory array, beginning at selected address
WRITE	0000 0010	Write data to memory array, beginning at selected address
WREN	0000 0110	Set the write enable latch (enable write operations)
WRDI	0000 0100	Reset the write enable latch (disable write operations)
RDSR	0000 0101	Read the Status register
WRSR	0000 0001	Write to the Status register

Table 3.3. Instruction set for 25LC640.

The program **25LC640.BAS** writes the string, "HELLO WORLD" to the first 11 locations within the eeprom. Then reads them back and displays the characters on a serial LCD connected to PortA.0. Figure 3.6 shows the eeprom's connections to the PIC.

The program is based around two subroutines, **EREAD**, and **EWRITE**, these perform the reading and writing to the eeprom.

The subroutine **EWRITE**, enables the eeprom by pulling the CS line low, then shifts out the WRITE ENABLE op-code (*6*). The CS line is then brought high to latch the instruction into the eeprom, and immediately pulled low again. The WRITE op-code (*2*) is then shifted out, along with the highbyte and lowbyte of the address variable, **ADDR**. The byte to be placed into the eeprom is then sent, this is held in the variable **E_BYTEOUT**. The CS pin is returned to its high position (*disabling the eeprom*), and a delay of 5ms is executed, allowing the byte to be written to the eeproms memory array.

The subroutine, **EREAD**, brings the CS line low, enabling the eeprom, and shifts out the READ op-code (*3*). The highbyte and lowbyte of the address variable, **ADDR** are then sent, and the byte from the eeproms memory array is shifted into the variable **E_BYTEIN**. The eeprom is then disabled by returning the CS line to its high state.
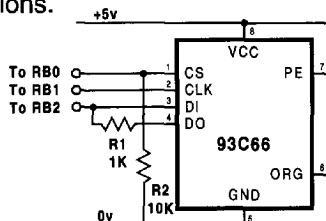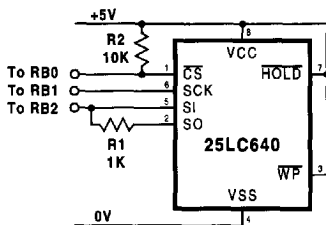

Figure 3.6. 25LC640 eeprom connections.

Resistor, R1 allows the data-in and the data-out lines to share the same PIC pin. Resistor, R2 is precautionary only, it ensures that when the circuit is first powered up the chip is disabled. This may be omitted if required.

As is common practice now, an include file has been added to allow the reading and writing of SPI eeproms. This is called **25XXXX.INC**, and contains the two subroutines, **EREAD**, and **EWRITE**. This should be loaded near the beginning of the main program, just after declaring the CS, SCK, and SI pin assignments: -

CS	*Var*	*PortB.0*	*' Assign the CS line to PortB.0*
SCK	*Var*	*PortB.1*	*' Assign the SCK line to PortB.1*
SI	*Var*	*PortB.2*	*' Assign the SI line to PortB.2*

Include "25XXXX.INC"   *' Load in the eeprom subroutines*

The SO line is automatically assigned to the same pin as the SI line, and the variables, **ADDR**, **E_BYTEIN**, and **E_BYTEOUT** are already pre-declared within the include file.

NOTE. Other SPI eeproms in the same device family as the 25LC640, such as the 25LC040 or the 25LC080, may also be used with these subroutines.

Section-4

Experimenting with Analogue to Digital Converters

Interfacing with the MAX186 ADC.
Using a 3-wire interface with the MAX186.
Using an external reference voltage for the MAX186.
Quantasizing the result.
Using the MAX187 ADC.
Interfacing to the MAX127 ADC.
Using the on board ADC.
Achieving greater accuracy through SLEEP.
Using the ADCIN command.
An alternative quantasizing formula.
Ironing out noisy results.

Experimenting with the PicBasic Pro Compiler

Interfacing with the MAX186 A/D Converter

Most real world applications work with analogue levels: - temperature, light, etc. This analogue data needs to be changed into a format that a PIC can understand, and use. This is normally achieved with an Analogue to Digital Converter (*ADC*). Some of the PIC series of microcontrollers have built in A/D Converters, but are limited to 8-bit or 10-bit resolution, in most cases this is enough, but for applications that require a higher resolution, an external A/D Converter is necessary.

The MAX186 is an eight channel, 12-bit, successive approximation A/D Converter, utilizing a 3, 4 or 5-wire interface (*clock, cs, data out, data in and optional strobe*). It may be configured to use its own internal reference voltage or an external source, and is capable of performing a conversion in 6 - 10us.

Figure 4.1 shows a demonstrational circuit to interface with the MAX186.

Before a sample can be read from the MAX186 a control-byte has to be sent, this control-byte, (*which is the purpose of pin DIN*), informs the chip as to which input to sample from, as well as what form of sampling to take (*bipolar or uni-polar*) etc. There is not enough room to go through all the features of the MAX186, The datasheet for the MAX186 may be found on the accompanying CDROM. However, table 4.1, shows a summary of each bit within the control-byte.

Bit	Name	Description
7 (MSB)	START	This must always be one, defines the beginning of the control byte
6 5 4	SEL2 SEL1 SEL0	These three bits select which of the eight channels are used for the conversion
3	UNI/BIP	1=unipolar, 0=bipolar. Selects unipolar or bipolar conversion mode. In unipolar mode, an input signal from 0V to VREF can be converted. In bipolar mode, the signal can range from -VREF/2 to +VREF/2.
2	SGL/DIF	1=single ended, 0=differential. Selects single-ended or differential conversions. In single-ended mode, input signal voltages are referred to AGND. In differential mode, the voltage difference between two channels is measured.
1,0 (LSB)	PD1 PD0	Selects clock and power-down modes. PD1 PD0 Mode 0 0 Full power-down 0 1 Fast power-down 1 0 Internal clock mode 1 1 External clock mode

Table 4.1. MAX186 control byte.

Experimenting with the PicBasic Pro Compiler

In this series of experiments, we will be using single-ended unipolar inputs (*0 to Vref*) and an internal clock. Therefore, the only part of the control-byte that needs to be changed are the channel selection bits (*SEL 0-2*), These bits are shown below in table 4.2.

SEL2	SEL1	SEL0	Channel
0	0	0	CH0
1	0	0	CH1
0	0	1	CH2
1	0	1	CH3
0	1	0	CH4
1	1	0	CH5
0	1	1	CH6
1	1	1	CH7

Table 4.2. MAX186 channel select bits.

The MAX186 has an internal reference of 4.096V, which means that a voltage of up to 4.095V on any of the input channels will result in the same value being sent serially to the PIC. The program **MAX186I.BAS** demonstrates this. The potentiometer VR1, acts as a variable potential divider connected to channel 0 of the MAX186, thus varying the voltage applied to the input, from 0 to 5V. This voltage is displayed on a serial LCD setup for Inverted 9600 baud, and connected to PortA.0.

The code for reading the MAX186 is in the subroutine **MAX186_IN**, but before this subroutine is called, the channel of interest is loaded into the variable **MAX_CH**. The subroutine uses the LOOKUP command, which holds all 8 combinations of the 3-bit channel addresses (*as in table 3*). The control-byte variable **CNTRL** is pre-loaded with the value %10001110, (*start, unipolar, single-ended and internal clock*), and the 3-bit address now held in **MAX_CH** is ORed with it, this superimposes the channel bits into the control-byte.

        Lookup Max_Ch,[0,64,16,80,32,96,48,112],Max_Ch
        Cntrl=%10001110 | Max_Ch   ' "OR" in the Channel bits

The MAX186 is then activated by pulling the CS pin low, and the control-byte is shifted out. Immediately after this, the 12-bit voltage conversion is shifted in, and the MAX186 is de-activated by bringing the CS pin high. The variable **MAX_VAL** now holds the 12-bit voltage reading (*0-4095*).

Experimenting with the PicBasic Pro Compiler

Low CS   *' Activate the MAX186*
Shiftout Din,Sclk,Msbfirst,[Cntrl\8]   *' Shift out the Control byte*
Shiftin Dout,Sclk,Msbpost,[Max_Val\12] *' Shift in 12 bits*
High CS   *' Deactivate the MAX186*

The SSTRB pin may be used to make sure that the MAX186 has finished a conversion before the 12-bit value is shifted in. This pin goes high when a conversion is complete, however the PIC is fast enough in most cases to just ignore this pin: -

While SSTRB=0:Wend   *' Wait for end of conversion*
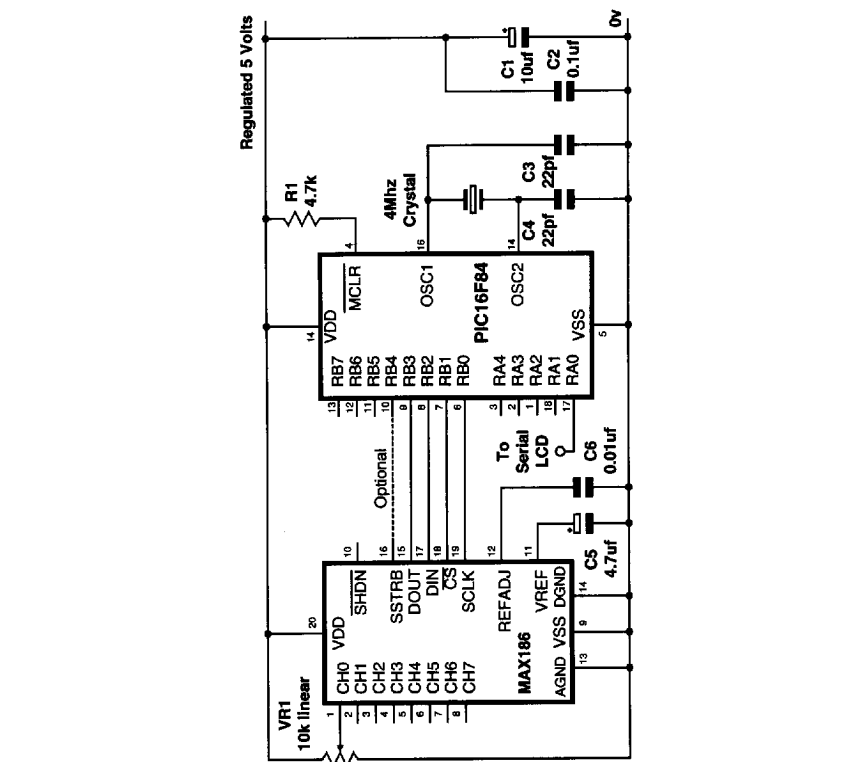
Figure 4.1. MAX186 demonstration.

Using a three wire interface with the MAX186

Using a 5-wire interface to demonstrate the use of the MAX186 is acceptable, but in normal use we only require 3 wires. This is possible due to the PIC's ability to change its pin state from input to output almost instantaneously, which means we are able to connect the MAX186's DIN and DOUT pins together, R1 is in place to limit the current flow between the PIC I/O pin and the MAX186's data output, in case a programming error causes a bus conflict, this happens when both pins are in output mode and in opposite states (1 vs 0). Without R1, large currents would flow between the pins, possibly causing damage to one if not both of the devices. We already know that the SSTRB pin may be omitted. This leaves just 3 pins used by the PIC, and a small change of code.

The program **3-WIRE.BAS** shows how the 3-wire interface is used, and figure 4.2 shows the new layout for the MAX186.
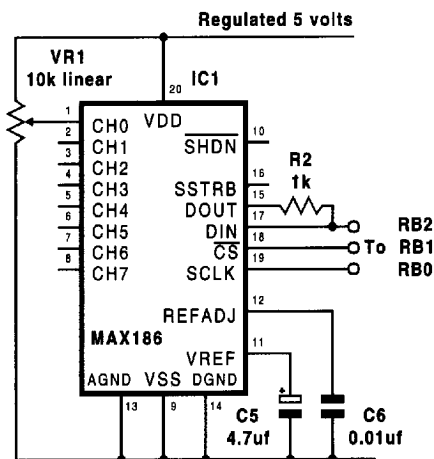
Figure 4.2. MAX186 3-wire interface.

Using an external VREF for the MAX186

As mentioned earlier, because of its internal voltage reference the MAX186 gives a full-scale reading of 4.095V. However, any voltage above this is not converted. If the full-scale reading needs to be lesser or greater than this voltage, an external voltage reference is required. This can take the form of a simple potentiometer, acting as a variable potential divider, connected to the Vref pin (*crude, but effective*), as in figure 4.3. Or the Vref pin can be connected to Vdd, (*where Vdd is regulated 5V*), as in figure 4.4.
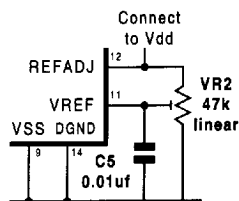
Figure 4.3 Variable Vref.
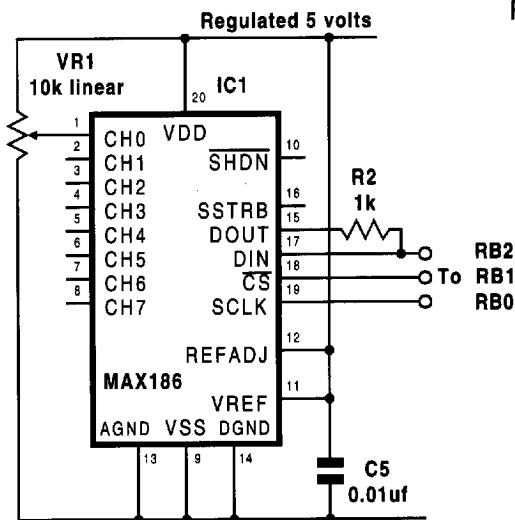
Figure 4.4. MAX186 external Vref connections.

Experimenting with the PicBasic Pro Compiler

Quantasizing the result

When the Vref pin is connected to Vdd, the full-scale reading of 4095 now represents 5V, so the output from the A/D, no longer represents the input i.e. 2000 is no longer 2.00V. This is because our analogue input contains an almost infinite number of possible values between 0 to 5V. However, the resolution of the MAX186 is 12-bits (*4096*), which forces the A/D to use each of its possible combinations to represent a segment of the analogue input.

For example, if we were converting a 0 to 5V analogue input using a 4-bit A/D. The 4-bit binary number would represent a range of 0-15. Dividing the 5V analogue range into 15 equal segments would result in approximately .33V per segment. These segments are called *quanta levels*. To calculate the *quanta level* for the MAX186 we need to divide the Vref voltage (*+5V in this case*) with the resolution used, which is 4096: -

$$quanta\ level = VREF\ /\ A/D\ resolution$$

Therefore: -

$$quanta\ level = 5\ /\ 4096$$

This gives us a *quanta level* of .0012207V, however, because the compiler only works with real numbers (*integers*), this is too small a value for it to handle, therefore, we will round it up to a more manageable value of 123, one has been added to the final quanta level to take into account that the compiler truncates (*rounds down*) any result of a division. We now have our *quanta level*. To calculate the actual voltage on the input of the A/D we use: -

$$Actual\ voltage = Result\ of\ conversion\ *\ quanta\ level$$

Lets suppose a conversion has taken place and the result returned is 2382, our calculation will now be: -

$$Actual\ voltage = 2382\ *\ 123$$

This would give a result of 292986, but this value is too large for the compiler to handle, so one part of the calculation needs to be reduced.

To acheive more accurate results it would be better to reduce the larger of the two numbers. Therefore our calculation now looks like this: -

Actual voltage = (2382/10) * 123

The actual voltage is now 29298.6, but because the compiler handles arithmetic with integer values only and also truncates, the actual result placed in the variable **MAX_VAL** is 29274.

The value 29274 is a nice real number to work with inside the code itself, but for display purposes it is more meaningful to view it as 2.9274 Volts. Therefore we must split off the numbers to the right of the decimal point, luckily, but not surprisingly the compiler has a command to calculate the integer remainder of a division. The operator for division is / and the operator for calculating the remainder is //.
For example: -

The integer calculation, *VOLTS = 29274 / 10000* would result in **VOLTS** holding the value 2.

And the integer calculation, *MILLIVOLTS = 29274 // 10000* would result in **MILLIVOLTS** holding the remainder of the calculation, which is 9274. In the demonstration programs the actual code looks like this: -

VOLTS = MAX_VAL / 10000
MILLIVOLTS = MAX_VAL // 10000

So now we have two new variables, **VOLTS** and **MILLIVOLTS** and we can display them with a decimal point placed in-between: -

DEBUG dec1 VOLTS , ".", dec4 MILLIVOLTS, " Volts"

Which will display on the LCD

2.9274 Volts

The program, **MAX186E.BAS** demonstrates these calculations.

This formula is not only useful for the MAX186 demonstration, it works for all A/D Converters, whether 8, 10, 12 or 16-bit.

Experimenting with the PicBasic Pro Compiler

Interfacing with the MAX187 A/D Converter

The MAX187 is the little brother of the MAX186. It only has one input but still has a resolution of 12-bits and can use its internal 4.096V reference voltage, or and external source. The wonderful thing about this chip is its ease of use, as it has no control byte, it may be accessed with only three lines of code. Figure 4.5 illustrates its use with an internal Vref and figure 4.6 shows its external Vref counterpart. Note that the SHDN pin must be connected to Vdd to use the internal reference, and left unconnected to use an external source. The pins SCLK, CS, and DOUT connect to the PIC's PortB as in the previous section on the MAX186.
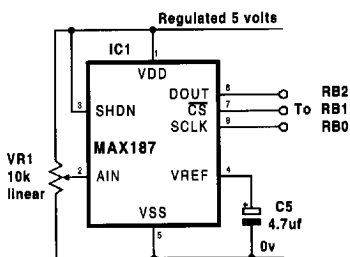
Figure 4.5. MAX187 internal Vref.   Figure 4.6. MAX187 external Vref.
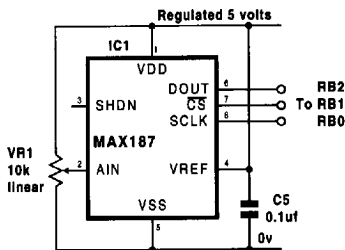
Program, **MAX187I.BAS** demonstrates how easy it is to use this device. It uses the internal Vref, therefore the voltage that can be read is 0 to 4.095V.

Program, **MAX187E.BAS** is based on an external Vref connected to VDD, this will give a range of 0 to 5V full-scale.

The subroutine **MAX187_IN**, enables the MAX187, by bringing the CS line low, then shifts in the 12-bit result, it then de-activates the chip by setting the CS line high. In the external Vref program the same formula for calculating the quanta levels are used as in the MAX186 code. The voltage reading is returned in the variable **MAX_VAL**.

```
Low CS                              'Activate the MAX187
Shiftin Dout,Sclk,Msbpost,[Max_Val\12]  ' Shift in 12 bits
High CS                             ' Deactivate the MAX187
Max_Val=(Max_Val/10)*Quanta         ' Quantasize the result
```

Interfacing with the MAX127 A/D Converter

The MAX127 is also an eight channel, 12-bit A/D Converter, but uses a 2-wire I^{2}C interface (*SCL, SDA*). What makes this A/D Converter different is its ability to convert a voltage greater than its supply line, without the use of an external Vref. This is due to the fact that the internal Vref is software controlled. Bit-3 of the control byte (*RNG*) configures the Vref to 5V or 10V full-scale.

Before a conversion can be read from the MAX127 a control-byte has to be sent, this informs the chip as to which input to sample from etc. Table 4.3 shows a summary of the bits within the control byte, and their purpose.

Bit	Name	Description
7 (MSB)	START	This must always be one, defines the beginning of the control byte.
6 5 4	SEL2 SEL1 SEL0	These three bits select which of the eight channels are used for the conversion.
3	RNG	Selects the full-scale input voltage. **0** = (0-5v), **1** = (0-10v)
2	BIP	Selects unipolar or bipolar conversion. **0** = unipolar, **1** = bipolar
1, 0 (LSB)	PD1 PD0	Selects power-down modes. PD1 PD0 Mode **0** **X** Normal operation **1** **0** Standby power-down mode **1** **1** Full power-down mode

Table 4.3. MAX127 control byte.

In this experiment, we will be using the unipolar inputs (*0 to Vref*), and the 5V full-scale conversion, therefore, the only part of the control-byte that needs to be changed are the channel selection bits (*SEL 0-2*), These bits are shown below in table 4.4.

SEL2	SEL1	SEL0	Channel
0	0	0	CH0
0	0	1	CH1
0	1	0	CH2
0	1	1	CH3
1	0	0	CH4
1	0	1	CH5
1	1	0	CH6
1	1	1	CH7

Table 4.4. MAX127 channel select bits.

Experimenting with the PicBasic Pro Compiler

MAX127 five Volt full-scale reading

Figure 4.7 shows the circuit for the MAX127, using the 5V internal reference. The potentiometer VR1, acts as a variable potential divider connected to channel 0 of the MAX127, thus varying the voltage applied to the input, from 0 to 5V. SCL and SDA connect to RB0 and RB1 of the PIC, as in the MAX186 demonstration. R1 is a pullup resistor required by the I²C bus protocol.

Figure 4.7. MAX127 5 Volt reference.

The program **MAX127_5.BAS**, demonstrates the use of the above circuit. The input channel of interest is loaded into the variable **MAX_CH** and the subroutine **MAX127_IN** is called. This subroutine shifts the channel bits into their correct place within the control byte, and sets bit-7, which must be a 1 (*see tables 5.3 & 5.4*).

The slave address of the device is then sent, to make sure that we are talking to the correct device on the I²C bus, and then the control byte is sent. The same slave address is sent, before the 12-bit result of the conversion is read in. The I2CREAD command reads in a full 16-bit word, so the result has to be shifted 4 places to the right to correct this. The quanta level calculation is then carried out, and the result is placed in **MAX_VAL**.

MAX127 ten Volt full-scale reading

As mentioned at the start of this experiment, the MAX127 is capable of converting a voltage that is greater than its power supply, upto 10V in fact. This is achieved by setting bit-3 of the control byte to 1, figure 4.8 shows a demonstration circuit for this.
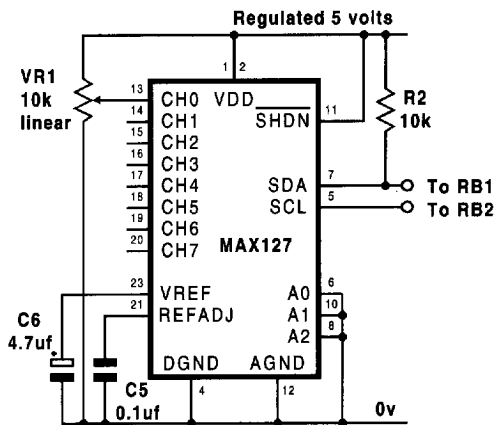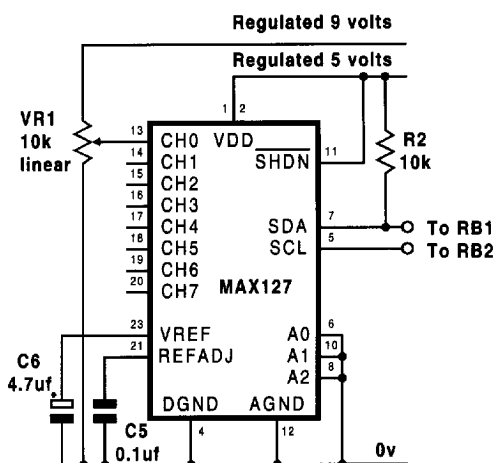

Figure 4.8. MAX127 10 Volt reference.

The program **MAX127_9.BAS**, demonstrates the use of the above circuit. The program is basically the same as **MAX127_5.BAS**, except that within the subroutine **MAX127_IN**, bit-3 of the control byte is set to 1. And because we are converting a voltage of upto 10V, the quanta level is also changed from 123 to 245 (*10V/4096*).

Experimenting with the PicBasic Pro Compiler

Using the on-board Analogue to Digital Converter

The ADCIN command takes a lot of the work away from accessing the on-board Analogue to Digital Converter, however to make efficient use of this command the principals behind using the ADC need to be understood. We shall take a look at the procedure for reading an analogue voltage, the *old fashioned* way. Then we shall look at the ADCIN command itself.

The PICs we shall be using are the new 16F87X range, these have an on-board 10-bit successive approximation ADC, which uses a bank of internal capacitors that become charged by the voltage being sampled. The 28 pin devices have five channels of ADC, while the 40 pin devices have eight channels.

The PIC powers up with all the ADC pins configured as analogue inputs. This may be acceptable if all the channels are being used for analogue purposes. However, if only a few of them are for analogue and the rest are to be used as digital lines then the first 4-bits (*PCFG*) of the ADCON1 register need to be manipulated. There seems to be no pattern involved with these bits, therefore table 4.6 must be used to determine which bits to set or cleared for a specific input configuration.

PCFG	AN7	AN6	AN5	AN4	AN3	AN2	AN1	AN0	VREF+	VREF-
0000	A	A	A	A	A	A	A	A	AVdd	AVss
0001	A	A	A	A	Vref+	A	A	A	AN3	AVss
0010	D	D	D	A	A	A	A	A	AVdd	AVss
0011	D	D	D	A	Vref+	A	A	A	AN3	AVss
0100	D	D	D	D	A	D	A	A	AVdd	AVss
0101	D	D	D	D	Vref+	D	A	A	AN3	AVss
011X	D	D	D	D	D	D	D	D	---	---
1000	A	A	A	A	Vref+	Vref-	A	A	AN3	AN2
1001	D	D	A	A	A	A	A	A	AVdd	AVss
1010	D	D	A	A	Vref+	A	A	A	AN3	AVss
1011	D	D	A	A	Vref+	Vref-	A	A	AN3	AN2
1100	D	D	D	A	Vref+	Vref-	A	A	AN3	AN2
1101	D	D	D	D	Vref+	Vref-	A	A	AN3	AN2
1110	D	D	D	D	D	D	D	A	AVdd	AVss
1111	D	D	D	D	Vref+	Vref-	D	A	AN3	AN2

A = Analogue input   D = Digital input

Table 4.6. PCFG0 to PCFG3 configuration.

The port pins that are desired as analogue inputs must also have their TRIS value set as input (*1*).

The channel of interest is chosen by bits 3 to 5 of the ADCON0 register (*CHS2: CHS0*). Table 4.7 shows their arrangement for a specific channel.

Bits 5..3	Channel selected	Pin name
000	Channel 0	RA0/AN0
001	Channel 1	RA1/AN1
010	Channel 2	RA2/AN2
011	Channel 3	RA3/AN3
100	Channel 4	RA5/AN4
101	Channel 5	RE0/AN5 (only on 40 pin)
110	Channel 6	RE1/AN6 (only on 40 pin)
111	Channel 7	RE2/AN7 (only on 40 pin)

Table 4.7. Channel selection bits.

The 10-bit result is held in the registers ADRESH and ADRESL. Bit ADFM (*ADCON1.7*), dictates whether the results will be left justified (*ADRESH holding lsb*) or right justified (*ADRESL holding lsb*). Setting ADFM will enable right justification (*normal*), while clearing ADFM will enable left justification.

The ADC's clock source must now be chosen, this is selected by bits 6 and 7 of the ADCON0 register (*ADS1: ADS0*). The four choices are shown below in table 4.8.

Bits 7..6	Clock type selected
00	2/Fosc
01	8/Fosc
10	32/Fosc
11	FRC (Internal RC oscillator)

Table 4.8. Clock selection bits.

The ADC's conversion time per bit is defined as T_{AD}. For correct operation, the ADC requires a minimum T_{AD} of 1.6us. Which means we must be very careful when choosing the clock source, a wrongly configured clock will result in reduced ADC resolution or non-at all.

To calculate the T_{AD} for a specific oscillator we can use the following formula: -

$$T_{AD} = x / Fosc$$

Where x = 2, 8, or 32, and Fosc is in mHz

Experimenting with the PicBasic Pro Compiler

For example, using a 20mHz crystal, we can choose which clock source is suitable by changing the value of x until the result is 1.6us or over: -

$$T_{AD} = 32 / 20 == 1.6us$$
$$T_{AD} = 8 / 20 == 0.4us$$

We can see from the results that a clock source of 8/Fosc will be too fast for the ADC to fully make a conversion. However, a clock source of 32/Fosc is perfect.

When FRC is selected as the clock source, the T_{AD} time is approximately 2 - 6us.

The ADC module is now ready to be enabled, this is done by setting the ADON bit (*ADCON0.0*)

To allow the internal *sample and hold* capacitors time to charge, we must wait a specific time before actually making a conversion. This time period depends on the impedance of the source being sampled, as well as the temperature of the PIC itself, however, a delay of between 2 to 20us will suffice in most cases.

We are now ready to take a sample, this is accomplished by setting the GO_DONE bit (*ADCON0.2*)

The conversion must be given time to complete, this may take the form of a delay after the GO_DONE bit is set, or the GO_DONE bit may be polled to see if it is clear. The latter is the best and most accurate method as the GO_DONE bit is cleared by hardware after completion of a conversion.

To reduce current consumption, we can now disable the ADC by clearing the ADON bit (*ADCON0.0*) The 10-bit analogue to digital conversion result is now held in the registers, ADRESH and ADRESL.

Program **10BITADC.BAS**, illustrates the use of the above technique. And figure 4.9 shows the circuit layout for a PIC16F876. As the potentiometer (*VR1*) is turned towards the +5V or 0V line the result will increase or decrease. This will be displayed on a serial LCD, configured for N9600 baud, connected to PortC.7.

Experimenting with the PicBasic Pro Compiler

Achieving greater accuracy through SLEEP

According to the PIC datasheets, a more accurate sample is obtained when the PIC is placed in sleep mode because the switching noise caused by the PIC's internal registers is minimized. Placing the PIC into low power mode is discussed with more detail in section-10, and this has many similarities.

Three new control bits are used for waking the PIC when the ADC has taken a sample. These are: -

PEIE (*INTCON.6*). Peripheral interrupts are enabled when set, such as the ADC, MSSP etc. When cleared the interrupts are disabled.

ADIE (*PIE1.6*). When set, the ADC interrupt is enabled, and disabled when cleared.

ADIF (*PIR1.6*). This flag gets set when an ADC interrupt has occurred, in other words when the ADC has finished taking a sample. This flag is mainly of use when an interrupt handler is implemented.

Figure 4.9 and program **ADC_SLP.BAS** demonstrate the SLEEP process. The first thing the code does is disable global interrupts by clearing the GIE bit of INTCON (*INTCON.7*).

When the PIC is placed into low-power mode the external crystal oscillator is halted; therefore, the code attaches the ADC clock source to the internal RC oscillator by setting bits 6 and 7 of the ADCON0 register (*ADS1: ADS0*). Peripheral interrupts are then enabled by setting the PEIE bit. Then the ADIE bit is set which enables the ADC to actually wake the PIC.

When the RC clock source is selected for the ADC, the PIC waits one instruction cycle after the GO_DONE bit (*ADCON0.2*) is set. This allows the SLEEP instruction to be executed before a sample is started.

The SLEEP instruction then places the PIC into low power mode until the ADC has finished a sample, this is then displayed on the serial LCD and the whole process is repeated.

Experimenting with the PicBasic Pro Compiler

Using the ADCIN command

Now that we have a better insight into the on-board ADC, we can use the ADCIN command with more confidence and efficiency.

There are three defines used by the ADCIN command, these are: -

    Define   ADC_BITS
    Define   ADC_CLOCK
    Define   ADC_SAMPLEUS

The first define (ADC_BITS), is used to inform the compiler as to what resolution the on-board ADC is. Some PIC's have an 8-bit ADC, while the newer types have a 10-bit ADC, or 12-bits for the PIC16C77X devices.

The second define (ADC_CLOCK), selects the ADC's clock source (2/Fosc, 8/Fosc, 32/Fosc, or FRC). This was discussed earlier.

The third define (ADC_SAMPLEUS), informs the compiler how long to wait (in microseconds) to allow the internal sample and hold capacitors to charge before a sample is taken. This is the delay after the ADON bit is set, but before the GO_DONE bit is set.

Before the ADCIN command may be used, the pin of interest must be configured as an input, by setting its TRIS value to one.

Then the four input configuration bits (PCFG) of ADCON1 must be set or cleared (see table 4.6). This will configure the appropriate pins to digital or analogue.

The justification bit (ADFM) of ADCON1 must also be set or cleared. In normal operation, the ADFM is set, which enables right justification.

Finally, the ADCIN command itself is used, this will make a conversion from the chosen channel and place the result into the variable assigned. The ADCIN command uses a polling technique to determine if a conversion has been completed, therefore, no delay is required after its use.

Experimenting with the PicBasic Pro Compiler

Program **ADCIN.BAS**, illustrates how to use the ADCIN command. The main part of the program is shown below: -

```
PCFG0=0
PCFG1=1
PCFG2=1
PCFG3=1                    ' Configure for AN0 as analogue input
ADFM=1                     ' Right justified result in ADRESL and
                           ' ADRESH

Inf:   ADCIN 0,AD_Result   ' Place the conversion of channel-0
                           ' into AD_RESULT
       Debug I,Line1,#AD_Result," "   ' Display the result
       Pause 200                      ' A small delay
       Goto Inf                       ' Do it forever
```

The circuit in figure 4.9 is also used for the demonstration.

Figure 4.9. On-board 10-bit ADC.

An alternative quantasizing formula

In the previous demonstrations, we have only looked at the raw data presented from the ADC, where a conversion of 5V will produce a result of 1023. Quantasizing the result was discussed earlier in this section (*under, interfacing the MAX186*). However, a different technique will be discussed for the quantasizing of the 10-bit ADC. This makes use of the ' */ ' operator, which returns the middle 16-bits of a 32-bit multiplication. This will allow the compiler's integer maths to multiply a fractional constant.

Any quantasized result depends on the accuracy of the quanta level, which in this case is, (*5/1024*). This gives the result, .0048828125, clearly this is too small for the compiler's integer maths to use, therefore, we will move the decimal point right a few times, this will leave us with a quanta level of 4.8828125. To make the quanta level a real number we multiply it by 256: -

*4.8828125 * 256 = 1250*

We now have a nice real number for our quanta level. The formula for calculating the actual voltage is : -

*Actual voltage = Result of conversion */ quanta level*

For example, suppose we have taken a sample from the ADC and it has returned the result of 512, the calculation now looks like this: -

*Actual voltage = 512 */ 1250*

This will produce a result of 2500, or 2.5V. To achieve a slightly more accurate result, the result of the conversion needs to be increased by multiplying it by 10: -

*Actual voltage = (512*10) */ 1250*

Which will produce a result of 25000, again 2.5 Volts.

Program **Q_ADCIN.BAS**, illustrates the above method, using the circuit in figure 4.9.

Experimenting with the PicBasic Pro Compiler

Ironing out noisy results

Sometimes accuracy is of a premium, therefore, certain precautions have to be taken when using A/D Converters, especially if they are 10-bit or more types. Any inaccuracy will manifest itself as noise, this is when the LSB of the reading changes continuously from one value to another. The integer math used by the compiler irons out most of the noise, however, if you are using the raw data presented by the ADC then you must first find out where the noise is coming from.

A major cause of noise is inadequate decoupling of the power supply. This may be alleviated by the use of capacitors prolifically placed around the circuit, and located as physically close to the ADC as possible.

If the input to the ADC is not a rapidly moving signal then a capacitor should be placed from its input to ground, the value depends on the frequency of the signal being sampled, therefore, a trial and error method should be adopted (*a few thousand pF is normally sufficient*).

Also, when designing the PCB or stripboard for final construction, a large ground plane should be employed.

Always ensure that the supply line is well regulated and that if an external reference voltage is used it is precise. When prototyping your circuit on a breadboard, noise will be more apparent, therefore, if the decoupling and regulation of the power supply work well on this medium it will be minimized in the final product.

Another method for reducing the noise is a software one. Several samples are taken from the ADC, then averaged out. For instance, if we were taking samples from the built in 10-bit ADC, which has a range of 0..1023, we would sample the ADC 10 times, add them together and place them in a WORD variable, this will give us a maximum value of 10230, which is well within the 16-bit capabilities of the compiler.

When all the samples have been aquired, the variable can then be divided by the number of samples taken, which is 10 in our case. This will give us the average value that was sampled. This method is not 100% accurate, however, the results obtained are adequate for most practical purposes. The program **SAMPLING.BAS**, demonstrates the usefulness of this method.

Section-5

Experimenting with Digital to Analogue Converters

**Using the PWM command as a D/A Converter.
Controlling the hardware PWM modules.
Building an R-2R D-A Converter.
Interfacing to the MAX5352 D/A Converter.
Interfacing to the AD8402 digital potentiometer.**

Experimenting with the PicBasic Pro Compiler

As you would expect, a Digital to Analogue converter is the exact opposite of an Analogue to Digital converter. It takes a binary value and converts it to a voltage. There are several ways to achieve this, pulse width modulation is the simplest method, a resistor ladder is a slightly more refined way, and a separate IC is the most accurate type. In this section we will explore all three methods, including the PWM modules, incorporated in the new 16F87X range of microcontrollers.

Using the PWM command as a Digital to Analogue Converter

Because Pulse width modulation is relatively easy to implement with the compiler, it's often overlooked as a viable 8-bit digital to analogue converter, yet the results achieved are surprisingly accurate.

Pulse-width modulation (*PWM*) allows a digital device to generate an analog voltage. The idea is, that if you make a pin's output high, the voltage on that pin will be 5V. Output low will be 0V. However if you switch the pin rapidly between high and low so that it was high for half the time and low for half the time, the average voltage over time would be halfway between 0V and 5V (*2.5 Volts*). The ratio of highs to lows in PWM is called the duty cycle. The duty cycle controls the analogue voltage, the higher the duty cycle the higher the voltage. Since the PWM command uses a byte (*8-bits*) to control the duty cycle, we can resolve the voltage down to a value, defined by the function: -

Range of Output / Range of input

Where output is the 0..5V swing, and input is the 8-bit (*0-255*) value of duty, so *5V/256 = .0195* which means, for each 1-bit change in the duty, the output voltage will change by .0195V, this is called the quanta level. Therefore, based on a given input we can calculate the output voltage with the following formula: -

*Vout = duty * quanta level*

For example, a duty of 150 would result in an output voltage of 2.925V

*Vout = 150 * .0195, Vout now equals 2.925*

This is important to know but not terribly useful within our code, we need to know the value to place into duty that represents the voltage required on the output. The formula we will use is: -

$$duty = Vout / quanta\ level$$

Our quanta level worked out as .0195, however this number is too small for the compiler's integer calculations to handle, therefore we will scale it up to a more manageable 195. We will also scale up Vout for a more accurate result. So our formula now looks like this; -

$$duty = (Vout * 100) / 195$$

In order to convert the chopped PWM into a smooth analog voltage we need to filter out the pulses and store the average voltage. R2 and C3 in figure 5.1 form an R/C network. The capacitor holds the voltage set by PWM even after the instruction has finished. The length of time it will hold the voltage depends on how much current is drawn by any external circuitry connected to it. In order to hold the voltage reasonably steady, we must periodically repeat the PWM command to give the capacitor a re-charge. Just as it takes time to discharge the capacitor, it also takes time to charge it in the first place. The PWM command lets you specify the charging time in terms of cycles. To determine how long to charge the capacitor, use this formula: -

$$Charge\ time = 4 * R\ (in\ k\Omega) * C\ (in\ uF).$$

For instance, figure 5.1 uses a 10kΩ resistor and a 1μF capacitor: -

$$Charge\ time = 4 * 10 * 1 = 40,\quad which\ is\ 40ms.$$

Which means it will take 40 cycles to charge the capacitor, however, since the compiler's PWM command cycle time is dependant on the crystal frequency, (*a 4mHz crystal will give a single cycle time of 5*ms, *a 20mHz crystal will give a single cycle time of 1ms etc*). To give a cycle time of 40ms using a 4mHz crystal we use this formula: -.

$$Cycle = charge\ time / (20 / OSC)$$

This will give us a cycle time of 8 to place within the PWM command.

Experimenting with the PicBasic Pro Compiler

If we wanted to produce a voltage on PortB.0 of 2.5V with a 4mHz crystal, using a 10kΩ resistor and a 1uF capacitor, we would use: -

```
Vout            Var   Word      'Output voltage required
Duty            Var   Byte      'Duty variable for PWM command
Quanta          Con   195       'Our quanta level based on 5V

Vout = 250                      'We require 2.5V
Duty = (Vout * 100) / quanta    'Calculate the duty
Pwm PortB.0 , Duty , 8          'Output the voltage for 40ms
```

After outputting the PWM pulses, the compiler leaves the pin as an input. Which means the pin's output driver is effectively disconnected. If it were not, the steady output of the pin would discharge the voltage on the capacitor and undo the voltage setting established by PWM. The PWM charges the capacitor, and the load connected to your circuit discharges it. How long the charge lasts (*and therefore how often your code should repeat the PWM command to refresh the charge*) depends on how much current the target circuit draws, and how stable the voltage must be. If your load or stability requirements are more than the passive circuit of figure 5.1 can handle, an Op-amp follower may be added to the output of the R/C network. This is illustrated in figure 5.2.

The op-amp chosen must have rail-to-rail characteristics such as the National Semiconductor LMC662 or the Analogue Devices OP296; otherwise the maximum voltage swing is approx 1V to 3.9V. The use of 9V for the op-amp's supply allows the maximum output of 5V to be achieved; if the op-amp's supply was 5V, the maximum output would be approx 4.8V.

The program **8BIT_PWM.BAS**, simply outputs a voltage of 3.5V, and then pauses for 100ms, without the op-amp connected the LED flashes, as the PWM command is not being called in time to stop the capacitor from discharging due to the load taken by the led. With the op-amp follower the LED remains stable, as the op-amp now carries the load.

PWM demonstration circuits
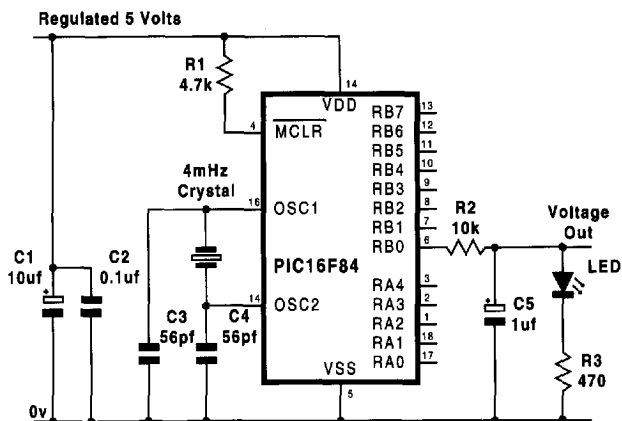
Figure 5.1. Unbuffered R/C network.
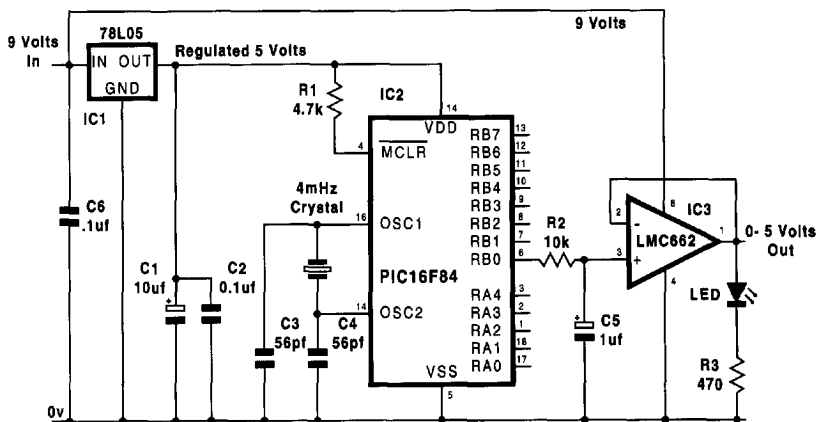
Figure 5.2. Buffered output.

Programs – 10BITPWM.BAS, HPWMTST.BAS and HPWM.INC

Controlling the 10-bit Hardware PWM

Although hardware PWM isn't uncommon on some PICs, the new PIC16F87X range have made this feature viable to experiment with because of their flash eeprom capabilities. In this experiment, we will be using the PIC16F876, but any of the 87X range may be substituted. The 16F876 has two hardware PWM modules; these are located on pins 12 and 13 and are named CCP1 & CCP2. Using these PWM modules isn't as easy to implement as the compiler's PWM command, several hardware registers need to be manipulated, and a reasonable amount of maths is required to realize the final PWM period and duty cycle. We will focus on just one of the two PWM modules, namely CCP1.

In order to generate a PWM signal from CCP1 a certain sequence of registers has to be set or cleared, therefore we will look at this sequence as a process of steps to carry out.

Step 1.
The CCP1 pin also aliases as PortC.2, therefore the first thing we have to do is configure it as an output, (*TRISC.2 = 0*).

Step2.
Both PWM modules are attached to TMR2, which means that both modules will share the same frequency. So TMR2 has to be initialised Firstly TMR2's prescaler ratio has to be established. This is accomplished by setting or clearing bits-0 &1 of the T2CON register: -

0-0 will set the prescaler ratio to 1:1 (TMR2 will tick on every instruction cycle).
0-1 will set the prescaler ratio to 1:4 (TMR2 will tick on every fourth instruction cycle).
1-X will set the prescaler ratio to 1:16 (TMR2 will tick on every sixteenth instruction cycle).

TMR2 now has to be turned on; this is done by setting bit-3 of T2CON, clearing this bit will turn TMR2 off.

Experimenting with the PicBasic Pro Compiler

Step3

The period (*or frequency*) of TMR2 now has to be established. This is placed in the PR2 register. The formula to accomplish this is: -

$$Period = (PR2+1)* 4 *(1/Fosc) * (TMR2\ prescaler\ value)$$

The '(*1/Fosc*)' part of the formula will always yield a fractional result i.e. (*0.25*). Therefore, in reality we are dividing each time we multiply by that number i.e. (*100 * 0.25 = 25*), which is the same as 100 / 4. This means that, '* (*1/Fosc*)' may be replaced with ' /Fosc '. Our formula now looks like this: -

$$Period = ((PR2+1)* 4 / Fosc) * (TMR2\ prescaler\ value)$$

So, for a 4mHz oscillator, prescaler set to 1:1, and PR2 = 255

$$((256 * 4) / 4) * 1 = 256$$

The period of the PWM will be 256us. In reality this is only as accurate as the crystal or resonator used.

To calculate the frequency that this represents we use the formula, (*1000 / Period*). This means our frequency (*in kHz*) will be (*1000 / 256*) which equals 3.90625kHz.

It would be beneficial to increase the frequency to as high as it would go, however, as the frequency increases so the resolution decreases. To calculate the resolution of a given frequency we use the formula: -

$$(log(\ Fosc/Fpwm\ )) / log(2)$$

Where Fosc is the crystal frequency and Fpwm is the frequency of the PWM signal, as calculated above. This formula can be broken down further by the fact that the log of 2 is a constant value of .301, therefore our formula now looks like: -

$$(log(\ Fosc/Fpwm\ )) / .301$$

Experimenting with the PicBasic Pro Compiler

So, for a frequency of 3.9kHz, using a 4mHz crystal, our formula is now.

$$(log(4000000/3900)) / .301 = 10.003$$

Which means that we have a resolution of 10-bits. That wasn't too bad, was it?

Step4

The 10-bit duty cycle value has to be loaded into two separate registers in a rather peculiar way. The most significant 8-bits of the duty have to be placed in the CCPRL1 register, and the first two bits of the duty have to be placed in bits-4 & 5 of the CCP1CON register. Therefore, we have to place bit-0 of the 10-bit duty into the CCP1CON register bit-4 and place bit-1 of the 10-bit duty into the CCP1CON register bit-5. This sounds more difficult than it actually is, as is demonstrated in the program **10BITPWM.BAS**. We now need to calculate the value to place into the duty registers to produce a required PWM voltage. Firstly, we need to calculate our quanta level for a 10-bit resolution (0 – 1023). This is more fully explained in the A/D section. However, the calculation is (5/1024) which equals .00488, we will move the decimal point right a few times and round up to compensate for the compiler's truncation of a division, which makes our quanta level 49. The formula for calculating the duty cycle for a given voltage is: -

$$duty = Vout / quanta\ level$$

Where Vout is a number from 1 to 500, we must increase the value of Vout, so as to increase the accuracy of our result, this will be done by multiplying it by 100. So our calculation within the program now looks like this: -

$$duty = (Vout*100) / quanta$$

Step5

All that needs to be done now is to turn the PWM on, this is achieved by setting bits-2 & 3 of the CCP1CON register. Clearing these bits will turn off the CCP1 PWM module.

If CCP2 module is being used then register CCP2CON should be exchanged for CCP1CON. And CCPRL1 should be changed to CCPRL2.

By placing different duty cycle values into the two 10-bit CCP registers, a different voltage will be produced from each CCP module. However, they will both share the same frequency as they are both attached to TMR2.

There is an Include file **HPWM.INC** on the disk that simplifies the use of the PWM modules. The include file has to be placed at the beginning of your program. Then prior to calling the **HPWM** subroutine, two variables have to be loaded. The variable **VOUT** holds the voltage output required, and the variable **CCP** holds the PWM module of interest: -

CCP = 0 will turn OFF both PWM modules.
CCP = 1 will output the voltage held in VOUT to PWM module 1.
CCP = 2 will turn PWM module 1 OFF
CCP = 3 will output the voltage held in VOUT to PWM module 2.
CCP = 4 will turn PWM module 2 OFF
CCP = 5 will output the voltage held in VOUT to both PWM modules

The program **HPWM_TST.BAS**, demonstrates the use of the include file.
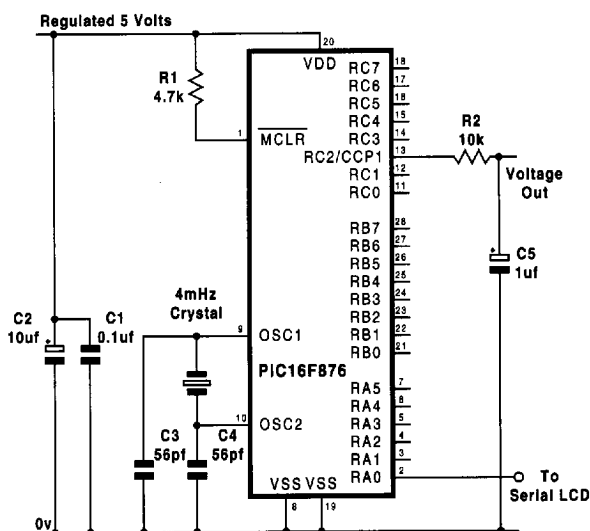
Figure 5.3. Hardware PWM circuit.

Building an R-2R Digital to Analogue Converter

The R-2R Digital to Analog converter is surprisingly simple to implement, with only 16 external resistors connected in the ladder formation, an extremely fast and reasonably accurate 8-bit D/A converter can be realized.

The R-2R arrangement of resistors works by dividing each voltage present at its inputs by increasing powers of two, and presents the total of all these divided voltages at its output. Since the PIC is capable of driving its outputs from 0 to 5V, the R-2R ladder converts the binary number on PortB into a proportional voltage from 0 to 5V in steps of approximately 20mV.

A great many commercial Digital to Analog converters work on this same principle, but also have internal voltage regulators and latches. Our demonstration doesn't require any of those things; therefore we can use the resistor array alone. Figure 5.4 shows the circuit for the R-2R Digital to Analog converter.
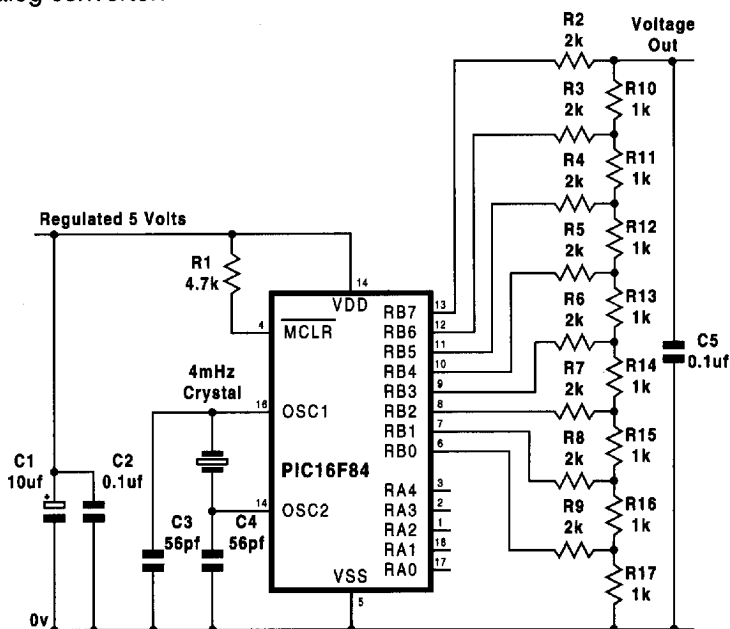
Figure 5.4. R-2R D/A converter.

The R-2R design has the advantage over PWM in that, as PWM is a train of pulses that require filtering the R-2R does not. Also, with the software implementation of PWM, this has to be refreshed periodically; the R-2R design will hold the output voltage until the value placed on PortB is changed. The accuracy of this design relies on the tolerance of the resistors used, but even with standard 10% resistors the results are acceptable. If difficulty in obtaining 2kΩ resistors is encountered, they may be substituted for 2.2kΩ types, with a very marginal decrease in accuracy.

The software to control the R-2R D/A converter is extremely easy to write, the formula to convert the binary representation presented on PortB into a voltage is basically the same as for the PWM command: -

$$Bval = Vout / quanta\ level$$

Where Bval is the 8-bit binary number that is placed onto PortB, we already know the quanta level for 5V and 8-bit (*195*). We will again scale up Vout for a more accurate result. So the calculation now looks like this: -

$$Bval = (Vout * 100) / 195$$

Program **R-2R.BAS**, demonstrates the use of the R-2R digital to analog converter. The output voltage required is loaded into the variable **VOUT**, and then a call is made to the subroutine **R2R**. This will calculate the value of **BVAL**, as in the above calculation, and output its result to PortB.

Experimenting with the PicBasic Pro Compiler

Interfacing to the MAX5352 D/A Converter

The MAX5352 is a 12-bit digital to analog converter, which uses a 3-wire serial interface (*SCLK, DIN, CS*). It has a built in op-amp follower that will allow a full-scale output of 0 to 5V. However it does not have an internal Vref, therefore an external source has to be applied. Also, the external Vref must be 1.4V below the Vdd rail. Which means the maximum output voltage, using this technique, is 3.6V, figure 5.5, shows the circuit for this. But all is not lost because, by adding two resistors, and making the Vref 2.5V, we can obtain the full-scale output of 0 to 5V, figure 5.6 shows the relevant circuit.

Although the MAX5352 only uses 12-bits to output a voltage, it requires all 16-bits to be sent, this is because, within the 16-bits, the three most significant bits, and the least significant bit are control flags. Table 5.1 shows the command bits within this word.

16_BIT SERIAL INPUT					FUNCTION
C2	C1	C0	D11.......D0	SO	
X	0	0	12 bits of data	0	Load input register; The DAC register is immediately updated (also exit shutdown)
X	0	1	12 bits of data	0	Load input register; The DAC register is unchanged
X	1	0	XXXXXXXXXX	X	Update the DAC register from the input register (also exit shutdown; recall previous state)
1	1	1	XXXXXXXXXX	X	Shutdown
0	1	1	XXXXXXXXXX	X	No Operation (NOP)

(X = don't care)   Table 5.1. Bits within the command byte.

The first demonstration uses an external Vref of 3.6V, this is accomplished, as shown in figure 5.5, by using a trimpot potentiometer to act as a variable voltage divider, which enables the Vref to be any voltage between 0 and 5V. For this demonstration, adjust the trimmer until 3.6V is obtained on pin 6 of the MAX5352.

Program **MAX5352R.BAS**, is for use with this circuit. The main program revolves around the subroutine **MAX_OUT**, but before this subroutine is called, the variable **VOUT** has to be loaded with the required output voltage, this can be any value between 0 and 360, where 360 is equal to 3.6V. The subroutine, multiplies **VOUT** by 10, which will give us our 12-bit value. It then shifts **VOUT**, one place to the left; this moves the 12-bits of voltage data into their correct place within the 16-bit word and ensures bit-0 is clear. It then clears bits-13..15 (*see table 5.1*), before shifting out the 16-bits.

Experimenting with the PicBasic Pro Compiler

The second demonstration of the MAX5352 uses a 2.5V Vref, but this time it is generated by a Texas instruments TLE2425, precision virtual ground IC. This IC, outputs a regulated 2.5V from a 5V input. Therefore, we are guaranteed a steady Vref, which will give us greater overall accuracy. In order for the MAX5352 to produce a maximum voltage swing of 0 to 5V, the internal op-amp is configured with a closed loop gain of two; this is accomplished by R2 and R3. Figure 5.6 shows the circuit for this technique.

Now that we are outputting a voltage greater than 3.6V, we need to use the formulas for quantasizing the result. Firstly, we need to calculate the quanta level (*see previous experiments*), which is (*5 / 4096*), this will give us a quanta level of 122. We now need to calculate the value to send to the MAX5352 which will represent the output voltage required, just to remind you, the formula for this is: -

$$Bval = Vout \,/\, quanta\ level$$

Where, *Bval* is the 12-bit binary word that will be sent to the D/A, and *Vout* is the required output voltage. In order to obtain a more accurate output voltage, we shall be using a slightly different approach to the calculations used within the compiler code. We will be using the divisional remainder operator, which is (//). Our formula from above can be broken down into three parts, the first will calculate the main body of the result, the second part will calculate the remainder, and the third part, adds these variables together, which will give us the final result.

For example, Let's say that we wish to produce an output voltage of 3.8V , the calculations within the compiler code will look like this: -

```
Vout = 380
Result = ((Vout * 100) / quanta level) * 10
Remainder = ((Vout * 100) // quanta level ) / 10
Vout = Result + Remainder
```

You will notice that the values have been scaled up by a factor of 10 or 100; this ensures that we will achieve a more accurate result from the divisions. This technique can be used for 8, 10, or 12-bit Digital to Analogue converters, if accuracy is of a premium.
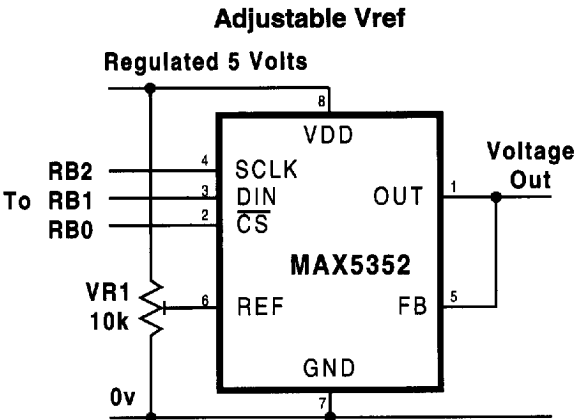
MAX5352 12-bit D/A converter circuits

Adjustable Vref

Regulated 5 Volts
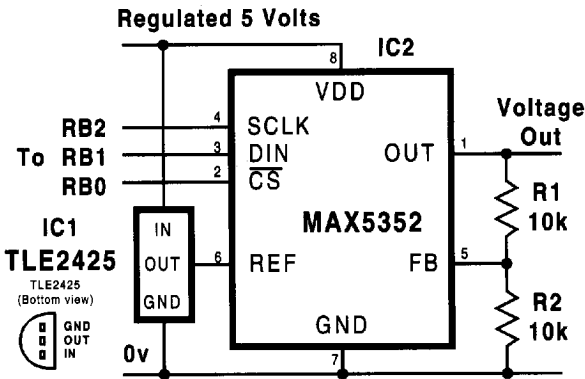

Figure 5.5.

2.5 Volt Vref with op-amp gain of x2

Regulated 5 Volts

Figure 5.6.

Experimenting with the PicBasic Pro Compiler

Interfacing to the AD8402 digital potentiometer

The digital potentiometer (*DP*) allows many of the applications of mechanical trimming potentiometers to be replaced by a solid-state device. The digital potentiometer has several benefits over its mechanical counterpart, including compact size, freedom from shock or vibration, and the ability to withstand oil, dust, temperature extremes, and moisture. The serial interface of a DP allows it to be electronically controlled by a microcontroller so that the user can adjust system parameters quickly and precisely. Some DP applications include: -

Power supply adjustment
Automatic gain control
Volume control and panning
LCD contrast control
Programmable filters, delays, and time constants

The two major configurations of the DP include the RHEOSTAT (*2-terminal configuration*) and the POTENTIAL DIVIDER (*3-terminal configuration*). And although the digital potentiometer is not specifically designed for use as a D/A converter, it is just one of several jobs that these remarkable devices are capable of achieving.

The Analog Device's AD8402 is a member of a series of digital potentiometers. This family consists of one, two, or four potentiometer devices. These are the AD8400, AD8402, and AD8403. Each of these devices come in a range of resistance values, 1kΩ, 10kΩ, 50kΩ, and 100kΩ. We will look at only one of these devices, namely the AD8402 with a 10kΩ fixed resistance per potentiometer.

The AD840X series provides 256-position digitally controlled variable resistors (*RDAC*). The RDAC is designed with a fixed resistor value that has a wiper contact that taps the resistor at a point that is determined by an 8-bit digital code. The resistance between the wiper and either endpoint of the fixed resistor varies linearly with respect to the digital code latched into the RDAC. Each RDAC offers a programmable resistance between the A terminal and the wiper (W) and the B terminal and the wiper (W). A unique switching circuit minimizes the inherent glitch found in traditional switched resistor designs by avoiding any make-before-break or break-before-make operation.

Experimenting with the PicBasic Pro Compiler

Each RDAC has its own latch to hold the 8-bit digital value defining the wiper position. These latches are updated from a 3-wire SPI (*serial peripheral interface*). Ten bits make up the data word needed for the serial input register. The first two address bits select an RDAC to modify and are then followed by eight data bits for the RDAC latch. The bits are clocked on the rising edge of the serial clock MSB (*most significant bit*) first. The CS pin starts a serial transaction by going low and then latches the 10-bits of data clocked by going back high.

The AD8402 provides enhancements over the AD8400, such as reset and shutdown. When the RS pin is pulled low, the values of the RDAC latches reset to a midscale value of $80 (*128*). When the SHDN pin is pulled low, the part forces the resistor to an end-to-end open circuit on the A terminal and shorts the B terminal to the wiper (W). While in shutdown mode, the RDAC latches can be updated to new values. These changes will be active when the SHDN pin is brought back high. Figure 5.6 shows the internals of the AD8402.
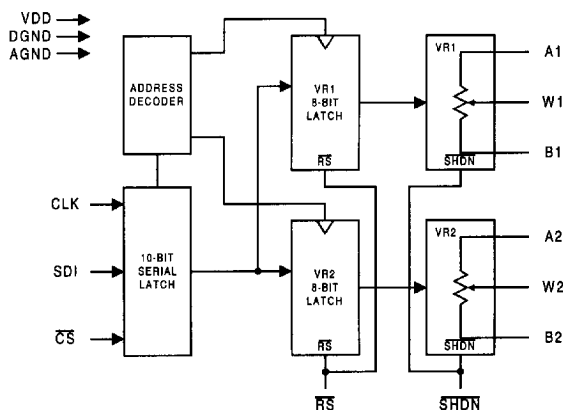
Figure 5.6. Block diagram of the AD8402 digital potentiometer.

Experimenting with the PicBasic Pro Compiler

The serial interface requires data to be in the format shown in table 5.2. First, the address bits of A1 and A0 must be sent, table 5.3 shows the format for the two address bits. The next eight bits are the data value to be latched into the selected RDAC.

ADDR		DATA							
B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
A1	A0	D7	D6	D5	D4	D3	D2	D1	D0
MSB	LSB	MSB							LSB
2^9	2^8	2^7							2^0

Table 5.2. Data format

A1	A0	RDAC decoded
0	0	RDAC #1
0	1	RDAC #2
1	0	RDAC #3 AD8403 only
1	1	RDAC #4 AD8403 only

Table 5.3. Address bit format.

Programming the Variable Resistor

The nominal resistance, R_{AB}, between terminals A and B of the AD8402 used in this discussion is 10kΩ. The R_{AB} of the RDAC has 256 resistive contact points that can be accessed by the wiper terminal plus the B terminal contact.

For an 8-bit value of $00, the wiper starts at the B terminal. The B terminal has an inherent resistance of 50Ω. The next resistive connection has a digital value of $01. It has a value equal to the B terminal resistance plus an LSB resistor value. For the 10kΩ part used, this LSB amount is equal to 10kΩ/256 or 39.0625Ω. Therefore, the resistive value at $01 is 89.0625Ω (*50Ω+39.0625Ω*). Each LSB increase moves the wiper up the resistor ladder until the last tap point is hit.
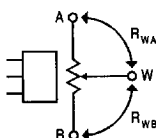
Figure 5.7. Variable resistor or (RHEOSTAT) configuration.

Experimenting with the PicBasic Pro Compiler

The resistance between terminal B and the wiper W can be described using the formula: -

$$R_{WB} = D * (R_{AB} /256) + R_B$$

where

R_{WB} = the resistance between the wiper W, and terminal B
D = digital value of the RDAC latch
R_{AB} = the nominal resistance between terminal A and B (*10kΩ*)
R_B = the resistance of terminal B (*50Ω*)

D	R_{WB} (Ω)	Output State
255	10010.9375	Full scale
128	5050	Midscale
1	89.0625	1st Least significant bit (LSB)
1	50	Zero-Scale

Table 5.4. R_{WB} Resistance values with R_{AB} = 10kΩ

Note that the zero-scale value produces a resistance of 50Ω. Care should also be taken to limit the current flow between the wiper and terminal B to a maximum of 5mA.

The RDAC is fully symmetrical. The resistance between the wiper W and terminal A also produces a resistance value of R_{WA}. When setting the resistance for R_{WA}, the digital value of $00 starts the resistance setting at its maximum value. As the digital value is increased, the R_{WA} resistance decreases. This can be described using the formula: -

$$R_{WA} = (256-D) * (R_{AB} /256) + R_B$$

where

R_{WA} = the resistance between the wiper W, and terminal A
D = digital value of the RDAC latch
R_{AB} = the nominal resistance between terminal A and B (*10kΩ*)
R_B = the resistance of terminal B (*50Ω*)

D	R_{WB} (Ω)	Output State
255	89.0625	Full scale
128	5050	Midscale
1	10010.9375	1st Least significant bit (LSB)
1	50.050	Zero-Scale

Table 5.5. R_{WA} Resistance values with R_{AB} = 10kΩ

Experimenting with the PicBasic Pro Compiler

In this experiment, we are only interested in using the AD8402 as a digital to analogue converter therefore; we shall look at a means of providing a variable voltage output. This is accomplished by the use of the potential divider configuration, illustrated in figure 5.8. The DP can easily be used to generate an output voltage proportional to the voltage applied between terminals A and B. If terminal A is connected to the +5V supply, and terminal B is connected to ground, the wiper voltage has a range of 0V up to 1 LSB less than +5V. Each LSB is equal to the voltage across terminals A and B divided by 256. The wiper's output voltage can therefore be calculated by using the following formula: -

$$V_W = (D/256) * V_{AB} + V_B$$

where

V_W = voltage on wiper
D = digital value of the RDAC latch
V_{AB} = voltage across terminal A and B
V_B = voltage at terminal B
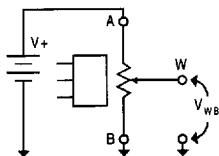
Figure 5.8. Potential divider configuration,

For example if we are using the 10kΩ part with +5V connected to terminal A, and a midscale value of $80 (128) is placed into the RDAC's latch. The voltage on the wiper terminal (V_W) would be: -

$$V_W = (128 / 256) * 5 = 2.5 \ Volts$$

In the above example, the ($V_{AB} + V_B$) part of the calculation may be replaced with 5 and 0 respectively, as the supply voltage (V_{AB}) will invariably always be +5V and the voltage on the B terminal (V_B) will usually be 0V.

However, we need to know what value to place into D (*RDAC latch*) to output a specific voltage.

Experimenting with the PicBasic Pro Compiler

The calculation we shall use is basically the same for the previous DAC experiments. We calculate the quanta level for 8-bits of data using a 5V supply (5/256). This gives us our usual quanta level of .01953, rounding this up and moving the decimal point to the right a few times, gives us our final quanta level of 196. Therefore, the calculation placed in the program will look like this: -

$$D = (V_W * 100) / quanta\ level$$

The value of V_W has been increased by a factor of 100, to enable a more accurate result.

Program **AD840X.BAS** and the circuit in figure 5.9 demonstrate the use of an AD8402 to output a voltage from 0 to 4.99V. It is centred around the subroutine **RDACOUT**, this subroutine outputs the 10-bit word to an AD8400, AD8402, or AD8403 digital pot. The internal RDAC of choice (1..4) is loaded into the variable **RDAC**, and the voltage to output is placed into **VOUT**. The subroutine calculates the value which is to be placed into the specific RDAC latch and checks the variable **RDAC**. A series of *if-thens* determine the address bits to set or clear. Then the chip is enabled by pulling the CS pin low and the 10-bits of data are shifted out. The chip is disabled by bringing the CS pin back high, and the subroutine is exited.

The main body of the program looks at the switches connected to PortB.3 (SW1) and PortB.4 (SW2). Depending on which of these is pressed the program will increase or decrease the output voltage.
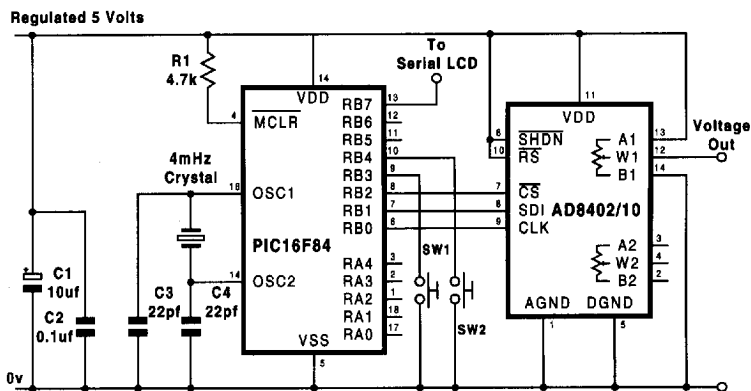
Figure 5.9. D/A converter using a digital potentiometer.

Section-6

Experimenting
with
Remote Control

Sony infrared remote control Receiver.
Assembler coded, Sony remote control Receiver.
Sony infrared remote control Transmitter.
Assembler coded, Sony remote control Transmitter.
Infrared Transmitter.
Infrared Receiver.
Transmitting and Receiving serial infrared.
418mHz, A.M. radio Transmitter.
418mHz, A.M. radio Receiver.

Experimenting with the PicBasic Pro Compiler

Sony, infrared remote control Receiver

There are three main protocols used for the transmission and reception of infrared signals. RC5, which is used by Philips, Rec-80, which is used by Panasonic, and the Sony format (*SIRCS*), which will be described here. Each form of infrared signalling has one thing in common, that is the use of modulated infrared light. Modulation is used to enable a certain amount of immunity from ambient light sources, especially fluorescent lighting. The frequency of modulation varies from 36kHz to 40kHz, depending on the manufacturer. An infrared detector is required to convert this modulated light into a digital signal. These are readily available in just about every TV, VCR, and satellite receiver made within the past 20 years. The type used for these series of experiments is the Siemens SFH506-38, (*unfortunately it's now out of production, but the alternatives are the SFH5110 or the LT-1059*). These are small three terminal devices that have a centre frequency of around 38kHz. However, just about any type may be substituted, the only difference that will be apparent will be a slight lack of range.

For the Sony protocol, the remote sends a start bit, sometimes called an AGC pulse, that is 2.4ms in length. This allows the receiver to synchronize, and adjust its automatic gain control, this occurs inside the infrared detector module. After the start bit, the remote sends a series of pulses. A 600us pulse represents a zero, and a 1200us pulse represents a one, there is a 600us gap between each pulse. Not all manufacturers stick stringently to these timings, so we will consider them as approximates. All of these pulses build up a 12-bit serial signal called a packet. This comprises of a 7-bit button value (*the remote button pressed*), and a 5-bit device value (*TV, VCR, etc*). The serial signal is transmitted with the least significant bit sent first.

Figure 6.1, shows the receiver circuit. PortA.0 is an output to a serial LCD module, set for inverted 9600 baud. The green LED flashes when a valid 12-bit packet is received.

The program **SONY_REC.BAS**, uses an include file, **SONY_RX.INC** to load in the receiver subroutine. When the subroutine **SONY_IN** is called, it returns three values. The button pressed on the remote is held in **IR_DATA**, the device code is held in **IR_DEV**, and the bit flag, **IR_VALID** is set if a valid signal was detected, and clear if not.

Therefore, our code will look like this: -

Again:
>   Gosub Sony_In   *' Receive the 12-bit packet*
>   If IR_Valid = 0 then goto Again *' Test if a valid packet received*

The three variables, **IR_DATA**, **IR_DEV**, and **IR_VALID** are already pre-declared within the include file. However, the Port and pin on which the infrared detector is connected must be changed within the Include file, if PortA.4 is not used.

The code within the subroutine **SONY_IN** works like this, First, it tests the input on which the infrared detector is connected, this will be low if we are already in the middle of a packet, (*note: the detector pulls its output low when a signal is detected*). If we are not already in the middle of a data packet, the header pulse is looked for using the PULSIN command; the result is placed in the variable, **ST**. Not all remotes send an exact 2.4ms header pulse; therefore we test for a pulse within the limits of 2ms to 2.7ms. The PULSIN command, used with a 4mHz crystal has a resolution of 10us; therefore a pulse of 2.4ms *(2400us)* will be returned as 240. If a header is not detected the flag **IR_VALID** is cleared, and the subroutine is exited. However, if a valid header is detected, a loop of 12 is setup, within this loop the individual data bits are inputted, again using the PULSIN command. We know that a 1 bit has a pulse duration of 1200us, and that a 0 bit has a duration of 600us, therefore we can split the difference and say that a pulse duration of over 900us must be a 1 bit, and any value under this, must be a 0 bit. The loop counter does this 12 times to build up the 12-bit packet. Each time a pulse of over 90 is received the appropriate bit of the variable **IR_WORD** is set, else it is cleared.

After the 12-bits have been received, the 7-bit button code and the 5-bit device code must be separated into their appropriate variables. To separate the button code, the variable **IR_WORD** is ANDed with %01111111, this has the effect of masking all but the first 7-bits, the result is then placed into the variable **IR_DATA**. To separate the device code, the variable **IR_WORD** is shifted right seven times, the 5-bit code now starts at bit-0 of **IR_WORD**, again it is ANDed, this time with %00011111, the result is then placed into the variable **IR_DEV**. The flag, **IR_VALID** is set, which indicates a valid packet has been received, then the subroutine is exited.

Experimenting with the PicBasic Pro Compiler

Assembler coded, Sony remote control Receiver.

The include file **ASM_RX.INC**, achieves the same results as the previous, BASIC coded version, except that it is a lot smaller, only 77 bytes, and is also only executable using a 4mHz crystal. Exactly the same variables are returned, namely, **IR_DATA**, **IR_DEV**, and **IR_VALID**. In addition, two new defines have been added, to inform the subroutine as to which pin the infrared detector is to be placed, these are: -

Define	*IRIN_PORT*	*Port*	*'Port for the IR detector*
Define	*IRIN_BIT*	*Bit*	*'Bit for the IR detector*

If these are omitted from the program, the default is PortA.4. As always, the include file must be placed at the beginning of your program to avoid any page boundary conflicts.
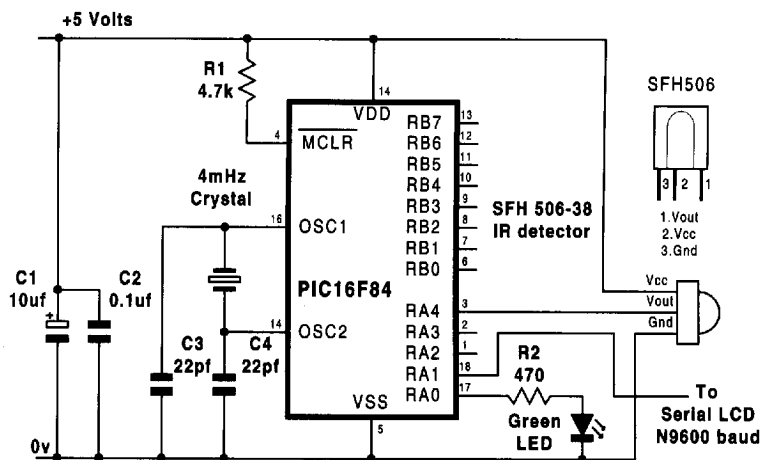

Figure 6.1. Sony, Infrared remote control Receiver.

Experimenting with the PicBasic Pro Compiler

Sony, infrared remote control Transmitter

The transmitter described here complements the previous receiver experiments. The transmitter sends out a 2.4ms header pulse, then a 12-bit word consisting of a 7-bit button code, and a 5-bit device code. Unlike other programs that require a gated oscillator to generate the 38kHz modulation, this is achieved within the code itself. 38kHz has a time duration of 26us; therefore, by turning the infrared LED on for 13us and off for 13us, a pulse of 38kHz is transmitted, (*Time (in us) = 1000 / Frequency (in kHz)*). This is accomplished by the subroutine, **IR_MOD**, this turns the infrared LED on, waits 8us, then turns the infrared LED off, and waits a further 7us. Assuming a 4mHz crystal, the commands LOW and HIGH each take 4us to complete, the NOP's take 1us each, and the GOSUB and RETURN commands take a further 3us. So altogether, we have a modulation time of (*2+4+8+4+7+1=26us*). If a PIC is used with more than 2k of ROM, then the compiler will place extra code to manipulate the PCLATH register for the GOSUB command. This will need to be compensated for, by reducing the amount of NOP's. The PAUSEUS command could not be used, as its minimum delay is 24us with a 4mHz crystal, hence the use of the NOP's. The **IR_MOD** subroutine is shown below: -

```
IR_Mod:
        High IR_LED         ' Turn on the IR_LED. (4 cycles)
@       Nop
@       Nop                 ' Each NOP takes 1 instruction cycle
@       Nop                 ' assuming a 4mHz crystal
@       Nop
@       Nop                 ' Remove for PICs with more than 2K ROM
@       Nop
@       Nop                 ' Do nothing for 8 cycles
        Low IR_LED          ' Turn off the IR_LED. (4 cycles)
@       Nop
@       Nop
@       Nop
@       Nop                 ' Remove for PICs with more than 2K ROM
@       Nop
@       Nop
@       Nop                 ' Do nothing for a further 7 cycles
        Return              ' Return from the subroutine, (1 cycle)
```

Experimenting with the PicBasic Pro Compiler

Transmitting the pulse durations, 600us, 1200us, and 2400us, is performed by the subroutine, **BURST**, this creates a loop of different lengths for each duration. The timings of this loop were accomplished by trial and error, as it's not as easy to count the cycles used in this subroutine as it was in **IR_MOD**. Within the loop, the infrared LED modulation subroutine is called, thus transmitting a modulated signal for a given time. The various pulse durations are placed in the variable, **B_TIME**.

Burst:
For B_Loop= 1 to B_Time	*' Loop for the pulse duration required*
Gosub IR_Mod	*' Modulate the IR LED, (2 cycles)*
Next B_Loop	*' Close the pulse duration loop*
Pauseus 600	*' Pause for 600us after every pulse*
Return	*' Exit the subroutine*

Now that we have the means to send the infrared signal, we need to build up the 12-bit word (*known as a packet*), which contains the button and device codes. Firstly, we need to place the two codes in their correct positions within the packet, (*the button code in the first 7-bits and the device code in the next 5-bits*). The variable **IR_WORD** holds the packet that will be sent. The device code, held in **IR_CMD** is first placed into the high byte of **IR_WORD**, then shifted right one bit. This will place it starting at the bit-8. Bit-7 of the button code, **IR_BYTE** is cleared as a precaution against a value greater than 127 being entered. Then it is ORed into **IR_WORD**, this has the effect of superimposing one value into another. We now have our two codes in their correct positions within **IR_WORD** ready to send. A for-next loop is setup to examine the first 12-bits of **IR_WORD**, if the bit is a 1 then **B_TIME** is loaded with the value for a pulse length of 1200us, else it must be a zero, and a pulse length of 600us is placed into **B_TIME**.

After all 12-bits have been sent, a delay of 35ms is implemented; this will bring the total delay time of the packet sent, to approx 45ms.

To use the infrared transmitter, place the button value within the variable **IR_BYTE**, and the device code within the variable **IR_CMD**.

IR_CMD = 1	*' Set device code to 1 (television)*
IR_BYTE = 18	*' Send volume up command*
Gosub Sony_Out	' Send the 12-bit packet

Experimenting with the PicBasic Pro Compiler

Program, **BAS_TX.BAS**, demonstrates the use of the infrared transmitter, with a 12-button keypad, as in figure 6.2. The keypad is used to send the channel buttons and volume up and down, " * " is used for volume down, and "#" is used for volume up. The lookup table converts the values returned from the **INKEYS** subroutine, into the value expected by the Sony device you wish to control, a television in this instance.

Program, **SNY_SEND.BAS**, does exactly the same as the above program, but using the include file **SONY_TRX.INC**.

Figure 6.2, shows the connections to the pic. Transistor, Q1 amplifies the output of the infrared LED, you will have noticed that there is no series resistor with the infrared LED, this is because the LED is never fully on, it is always modulated with a 38kHz signal. This acts as a form of PWM. If Q1 is omitted, the infrared LED may be connected directly to the pin of the PIC, however, this will result in a drastic lack of range. The green LED is illuminated whenever a signal is transmitted.
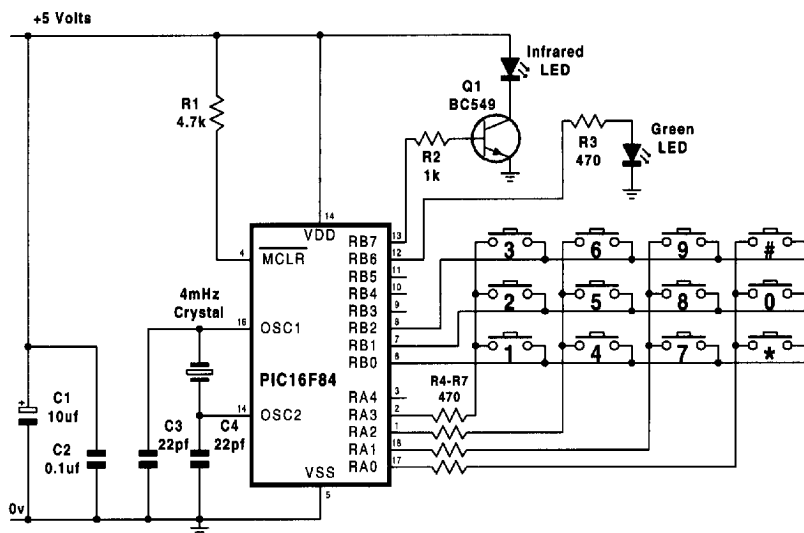
Figure 6.2. Sony, infrared remote control Transmitter.

Experimenting with the PicBasic Pro Compiler

Assembler coded, Sony infrared remote control Transmitter

This assembler coded transmitter uses the same principals as described for the BASIC coded version, but uses a lot less memory within the PIC. The assembler subroutine is transparent to your BASIC program as it is in the form of an include file, **SONY_TX.INC**, and a call to a subroutine, **SONY_OUT**. As with the receiver subroutine it is only compatible with a 4mHz crystal. The assemby code will not be explained, however it is fully commented if you wish to examine it more closely.

To use the infrared transmitter, place the button value within the variable **IR_BYTE**, and the device code within the variable **IR_CMD**. The variable names have been changed from the receiver routine to avoid any duplicate variable errors occurring if both are used within the same program. Again, there are two new defines added, these inform the subroutine which port and bit to place the infrared LED. These are: -

Define	*IROUT_PORT*	*Port*	*'Port for the IR LED*
Define	*IROUT_BIT*	*Bit*	*'Bit for the IR LED*

If these defines are omitted from your program the defaults are, PortA.0.

Program **SONY_TX.BAS**, demonstrates the use of the infrared transmitter, with a 12-button keypad, as in figure 6.2. The keypad is used to send the channel buttons and volume up and down, " * " is used for volume down, and "#" is used for volume up. The LOOKUP command converts the values returned from the **INKEYS** subroutine, into the value expected by the Sony device you wish to control, a television in this instance.

Experimenting with the PicBasic Pro Compiler

Infrared Transmitter

The previous two projects are ideal if a remote control handset is all that is being implemented. However, if a full 8-bit byte is to be sent or received then the project presented here can be used. Within the Include file, **IR_RX_TX.INC**, there are two subroutines, **IROUT**, which will transmit an 8-bit byte, along with a unique transmitter number, and **IRIN**, which will receive the IR signal from its complementary transmitter. Both subroutines are written in assembler, and are for use with a 4mHz crystal. However, this is transparent to your BASIC program, and all that is required are that a few variables be loaded, and a call made to the relevant subroutine. The added advantage is that, both the **IROUT** and **IRIN** subroutines combined, only use 112 bytes of ROM. The transmission and reception method used, is based on the Sony protocol, however, instead of sending 12-bits, 16-bits are sent. This means that a full 8-bits can be sent for the data byte, and another 8-bits can signify a unique number for each transmitter used. Four new defines have been added, to inform the subroutines of the port and pin to connect the infrared detector and the infrared LED. Two of these defines are for the transmitter subroutine, **IROUT** and these are: -

Define	*IROUT_PORT*	*Port*	*'Port for the IR LED*
Define	*IROUT_BIT*	*Bit*	*'Bit for the IR LED*

If the defines are not used in your program the default is PortA.0

To use the transmitter subroutine, load the byte to send into the variable **IR_BYTE**, and the transmitter id into **IR_ID**, then make a call to **IROUT**. For example: -

IR_ID = 2	*' This is transmitter 2*
IR_BYTE = 254	*' Let's send the value 254*
Gosub IROUT	*' Transmit the two bytes*

The two variables, **IR_BYTE** and **IR_ID** are pre-declared within the include file, **IR_RX_TX.INC**, therefore, they do not need to be declared within your program.

The circuit for the **IROUT** subroutine is the same as the Sony remote control transmitter, figure 6.2. But the keypad may be discarded.

Experimenting with the PicBasic Pro Compiler

Infrared Receiver

The receiver defines, again inform the **IRIN** subroutine as to which port and pin to place the IR detector, these are: -

Define	*IRIN_PORT*	*Port*	*'Port for the IR detector*
Define	*IRIN_BIT*	*Bit*	*'Bit for the IR detector*

If the **IRIN** defines are not used, the default is PortA.4.

To use the receiver subroutine, make a call to **IRIN,** and there are three variables returned, these are **IR_BYTE, IR_ID,** and **IR_VALID.** As you will have guessed, **IR_BYTE** contains the byte transmitted, and **IR_ID** contains the transmitter id value. **IR_VALID** is a bit variable, which returns the values 1 or 0. If a valid 16-bit packet has been received correctly, then this flag is set, however if a valid packet was received incorrectly it is clear. For example: -

Again:
Gosub IRIN   *' Receive a 16-bit packet*
If IR_VALID = 0 then goto Again   *' Check if packet is valid*
If IR_ID = 2 then   *' Check the TX ID code*
Do the code within the IF statement   *' Do this code if correct*
Endif

The circuit for the **IRIN** subroutine is the same as the Sony remote control receiver, figure 6.1.

Experimenting with the PicBasic Pro Compiler

Transmitting Serial infrared

The final method we shall look at for transmitting and receiving infrared signals, is that of normal RS232 serial protocol (i.e. *inverted 2400 baud etc*). This will allow us to send more than one byte at a time. However, we cannot simply connect an infrared LED to the PIC and invoke the SEROUT command, the LED must be modulated at 38kHz. Therefore, the transmitter subroutine has had to be written in assembler, but is compatible with 4, 8, 10, and 12mHz crystals. As always, the include file, **IRSEROUT.INC** must be placed at the beginning of your program. In addition, FIVE new defines have been added, which enable the **IRSEROUT** subroutine to be customized. The first two defines, configure the port and pin on which to connect the IR detector, these are: -

Define	*IRSEROUT_PORT*	*Port*	*'Port for the IR LED*
Define	*IRSEROUT_BIT*	*Bit*	*'Bit for the IR LED*

If these defines are not used in your program, the defaults are PortA.0

The third define, configures the desired transmission baud rate. There are four baud rates to choose from, namely, 300,600,1200, and 2400.

Define	*IRSEROUT_BAUD*	*Baud*	*'Desired baud rate*

If this define is omitted from your program the default is 1200 baud

The maximum baud rate achievable with any accuracy is 2400; this is because the components within the infrared detector module cause a finite delay between receiving the infrared signal and outputting the logic level. The baud mode is, inverted, 1 start-bit, 8 data-bits, and 1 stop-bit.

The fourth define, sets the delay between bytes transmitted. Sometimes the transmission rates of **IRSEROUT** may present characters too quickly to the receiver. Therefore, a delay of 1 to 255 milliseconds (*ms*), may be implemented.

Define	*IRSEROUT_PACING*	*1... 255*	*'delay between chrs (ms)*

If this define is not used, the default is 1ms

Experimenting with the PicBasic Pro Compiler

The fifth define, switches on or off a 3-byte header that precedes every data byte transmitted.

Define   IRSEROUT_HEADER 1 or 0   'Turn on/off header

The 3-byte header, consisting of "# O K", allows the receiver to adjust its internal AGC, and synchronize with the start of a transmission. Unlike async communications over wires, there are plenty of 38kHz modulated signals around, namely the TV remote. These can be picked up by our receiver and interpreted as valid signals, with disastrous results. Thus, we place a unique sequence of characters that signify that a signal from our transmitter has been sent. The likelihood of the same three characters being randomly produced is virtually non-existent. The internally produced header is useful if only one byte of data is being transmitted, otherwise, every byte sent will have a 3-byte header preceding it. To illustrate the use of the header characters, and to show how easy it is to transmit several bytes, your code could look something like this: -

IR_Byte = "#" : Gosub IRSerout	*' Send a three byte header*
IR_Byte = "O" : Gosub IRSerout	*' to synchronise the receiver*
IR_Byte = "K" : Gosub IRSerout	*' with the actual bytes sent*
IR_Byte = 127 : Gosub IRSerout	*' Send a byte with value 127*
IR_Byte = 254 : Gosub IRSerout	*' Send a byte with value 254*
IR_Byte = 2 : Gosub IRSerout	*' Send a byte with value 2*

The variable, **IR_BYTE** has to be pre-loaded with the byte to be transmitted, and then a call is made to **IRSEROUT**. If the header define is not used, the default is NO header. There is no need to declare the variable, **IR_BYTE** in your program, as it is already pre-declared within the include file. The program **SER_IR.BAS**, illustrates the use of the **IRSEROUT** subroutine.

Experimenting with the PicBasic Pro Compiler

Receiving Serial infrared

To receive the serial infrared signal, we simply use the compiler's SERIN2 or DEBUGIN commands. These are more desirable than the normal SERIN command, since they can automatically wait until the 3-byte header is found, using the WAIT operand: -

Serin2 PortA.4 , BAUD , [wait (" #OK ") , IR_Rcv]

This will wait for the characters, "#OK" to be received before it receives the actual byte, which it places into the variable **IR_RCV**. This helps to synchronize the start of the actual transmission, and also prevents false characters being interpreted as valid data.

To calculate the baud rate used in the SERIN2 command, the formula is *(1000000 / baud) – 20*, also the baud mode must always be set to True, this is the opposite of the transmitter's mode, because the infrared detector pulls its output low when it receives a signal, therefore, it inverts the incoming signal. The table below shows the value to place into the Constant **BAUD**, for the desired baud rate.

T2400 baud.......396
T1200 baud.......813
T600 baud........1646
T300 baud........3313

The program, **IRSERIN.BAS** illustrates one technique for receiving several bytes. The circuit for the receiver is the same as that for the Sony remote control receiver, figure 6.1.

Program – AM_TX.BAS

418mHz, AM Radio Transmitter

Remote control systems are becoming increasingly popular, and the introduction of pre-tuned radio modules and their ever decreasing prices has made radio a practical alternative to infrared. The advantage of radio is the ability of the signal to pass through objects and walls. Its range is also impressive, 100 metres or more (*in free space*) being normal. No licence is required in the UK, providing the radio modules operate on the 418mHz or 433mHz wavebands. The radio modules may be used in a similar way to those in the infrared remote control sections.

Although the modules described in this section are the a.m. type, the f.m. types may be directly substituted.

In order to carry information the required signal must be superimposed on the radio wave (*known as the carrier wave*). With Amplitude Modulation transmissions, it is the *amplitude* of the carrier wave that is made to change in accordance with the required signal. This is reasonably easy to generate, but can suffer from external interference.

AM-TX1- 418 Transmitter
The RF Solutions a.m. transmitter module, type AM-TX1-418, is a 2-pin device that is similar in appearance to a capacitor. It's incredibly simple to use, the standard circuit arrangement is shown in figure 6.3.
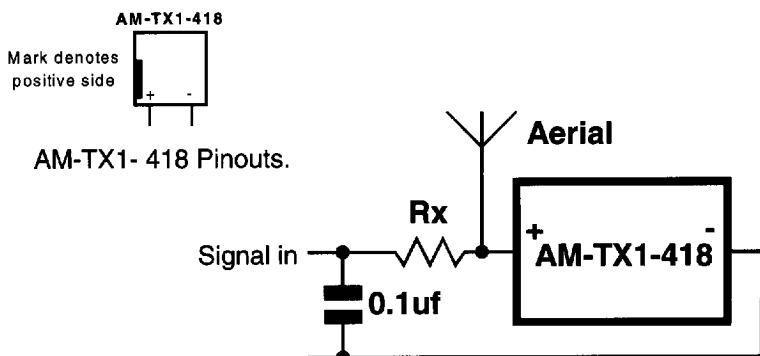
Figure 6.3. Basic circuit arrangement.

Only a few additional components are required, a capacitor which can be any value from 200pF to 0.1uF, and Rx. The value of Rx is chosen according to the supply voltage used in the circuit, (*between 3 and 12V*). The list below shows the values for each voltage used, as well as other specifications: -

Supply voltage	Resistor value
12V	2.2kΩ
9V	1.8kΩ
6V	1kΩ
4.5V or 5V	470Ω
3V	100Ω

Current consumption: 2.5mA (*typical*)
CMOS/TTL compatible input
Data throughput: 1200 baud (*2400 baud max*)

The AM-TX1-418 module requires an aerial which is slightly more difficult to set up than the AM-RT4-418. Two arrangements are illustrated in figure 6.4. A small variable capacitor having a 2pF to 5pF range is also required, and must be adjusted to provide the strongest signal. If no aerial or capacitor is used, a typical range is approx 5 metres.

MAX 700mm²

2 - 5pf

RF Ground

Tuned Loop Aerial

90mm MAX

2 - 5pf

RF Ground

Short Whip Aerial
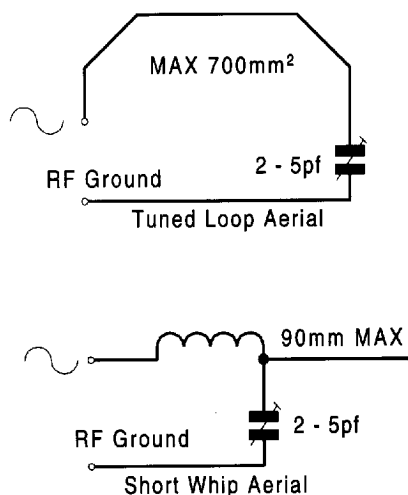
Figure 6.4. Aerial arrangements for the AM-TX1- 418 Transmitter.

Experimenting with the PicBasic Pro Compiler

AM-RT4- 418 Transmitter

An alternative 418mHz a.m. transmitter module is the RF Solutions, AM-RT4-418. This is housed in a D.I.L. package and its basic circuit arrangement and pinouts are shown in figure 6.5
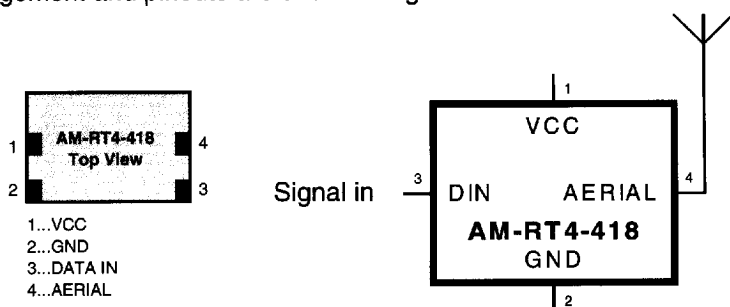
Figure 6.5. AM-RT4-418 Pinouts and Basic circuit arrangement.

The operating voltage for this module may be anything between 2 to 14V, it draws 4mA when a signal is being transmitted, and has a maximum data rate of 4kHz (*4800 baud max*). The aerial for use with this module may be a whip type or a helical coil. The helical coil consists of 34 turns of 0.5mm enamelled copper wire, close wound on a 2.5mm diameter former. This uses a lot less space than the whip aerial, however, its performance is a little inferior, and small adjustments to its length may be required. A whip aerial is the simplest type for this transmitter. It can be as simple as a piece of wire (*or pcb track*) 17cm long. The wire should be as straight as possible. There is no need for a variable capacitor with this transmitter module. Again, if an aerial is not used, the useful range is reduced to approx 10 metres.

Interfacing a transmitter module to the PIC is as easy as attaching its input to one of the PIC's outputs. There is no need to modulate the signal with 38kHz, therefore any of the SERIAL commands may be used, or the PULSOUT command, and with the added luxury of any desired oscillator frequency. The use of a synchronising header is always recommended when sending serial data, this can be as simple as the 3-byte header used in the serial infrared transmitter experiment. Without the synchronising header, random inputs could be interpreted as valid data. Other than that, these modules may be treated as if a wire interface was being used.

Experimenting with the PicBasic Pro Compiler

418mHz, AM Radio Receiver

There are three types of a.m. receiver available. They all have the same pin layouts and are interchangeable with each other. The three versions are: -

AM-HRR1- 418: This is the least expensive, and although it was superseded by the HRR3 type, its performance is surprisingly good.

AM-HRR3- 418: As above, but is laser trimmed for greater accuracy and less frequency drift.

AM-HRR5- 418: The same laser trimmed design as above, but with a lower current consumption (0.5mA).

The three receivers have the following specifications: -

Supply voltage: 4.5V to 5.5V
Supply current: 2.5mA (HRR5 version: 0.5mA)
CMOS/TTL compatible output
Maximum data rate 2kHz (*in practice 4800 baud has been achieved*)

The pin layout and basic circuit arrangement for all three receivers is shown in figure 6.6. The aerial for these receivers is the same as for the **AM-RT4- 418** transmitter.
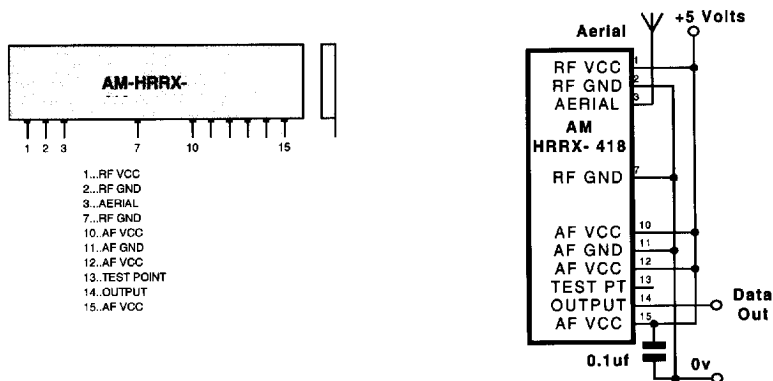
Figure 6.6. AM-HRRX-418 pinouts and basic circuit arrangement.

Experimenting with the PicBasic Pro Compiler

As with the transmitter modules, interfacing the receiver to the PIC is a simple case of connecting its data out pin to one of the PIC's pins. Then by using one of the compiler's many serial-in commands (*DEBUGIN, SERIN etc*), the data from the transmitter is received.

The receivers discussed may receive data up to a limit of 4800 baud; however, there are receivers available that are capable of receiving data many times faster than this, along with their corresponding transmitter. But, as the transmission rate goes up so does the price. With good aerial design, the simple and inexpensive 418mHz modules are capable of remarkable distances with a high degree of accuracy.

The accompanying CDROM has a comprehensive set of datasheets and application notes for most of the more common transmitter/receiver modules available.

Section-7

Temperature Measurement Experiments

Interfacing with the DS1820.
Dallas 1-wire interface principals.
Interfacing with the LM35 temperature sensor.

Experimenting with the PicBasic Pro Compiler

Interfacing with the DS1820, 1-wire temperature sensor

The Dallas DS1820 is a complete digital thermometer on a chip. It can measure temperatures from –55°C to +125°C in 0.5°C increments.

The DS1820 communicates with the PIC through a 1-wire connection. This has a master, which is the PIC, and one or more slaves. The DS1820 acts as a slave, receiving commands then transmitting its data back to the master. The 1-wire system requires strict prototocols for transmission and reception of data, these are called *time-slots*.

1-wire interface principals.

All transactions on the 1-wire bus must begin with the master sending an initialisation sequence.

The INITIALIZATION SEQUENCE consists of the master pulling the DQ line low for a minimum of 480us. The master then releases the DQ line (*which is held high via a pullup resistor*) and goes into receive mode. After detecting the rising edge on the DQ line, the DS1820 waits 15..60us, then transmits its presence pulse. This is a low signal, which lasts for 60..120us. If for any reason the DS1820 did not, or is not capable of sending a presence pulse the DQ line will remain high and an error flag may be set: -

```
DS_Init:
        Low DQ                ' Set the data pin low to initialize
        Pauseus 500           ' Wait for more than 480us
        DQ_DIR=1              ' Release the data pin (set to input for high)
        Pauseus 100           ' Wait for more than 60us
        If DQ=1 then          ' Is there a DS1820 detected?
        DS_Valid=0           ' If not, then clear DS_VALID flag
        Return               ' Return with DS_VALID holding 0 (error)
        Endif                ' Else
        Pauseus 400           ' Wait for end of presence pulse
        DS_Valid=1           ' Set DS_VALID flag
        Return               ' Return with DS_VALID holding 1(no error)
```

Experimenting with the PicBasic Pro Compiler

The DS1820 as with all the 1-wire devices operate with instructions, these are transmitted by the master immediately after the bus is initialised. The DS1820 understands eleven instructions (*op-codes*), the most common of these are explained below.

SKIP ROM [CCh]
This command allows the master to access the memory functions without providing the 64-bit rom code. If more than one slave is present and a read command is sent after the Skip rom command, data collision will occur on the bus as multiple slaves transmit simultaneously.

READ ROM [33h]
This command allows the master to read the DS1820's 8-bit family code, (*a unique 48-bit serial number*), and 8-bit CRC. This command can only be used if there is a single DS1820 on the bus. If more than one slave is present, a data collision will occur when all slaves try to transmit at the same time.

READ SCRATCHPAD [BEh]
This command reads the contents of the scratchpad. Reading will begin at byte 0, and will continue through the scratchpad until the ninth (*byte-8, CRC*) byte is read. If not all locations are to be read, the master may issue a reset to terminate the reading at any time.

COPY SCRATCHPAD [48h]
This command copies the scratchpad into the eeprom of the DS1820, storing the temperature trigger bytes in non-volatile memory. If the master issues read time slots following this command, the DS1820 will output a zero on the bus as long as it is busy copying the scratchpad to eeprom, it will return a one when the copy process is complete. If the DS1820 is parasite powered, the master has to enable a strong pullup for at least 10*ms* immediately after sending this command.

CONVERT [44h]
This command begins a temperature conversion. No further data is required. The temperature conversion will be performed, then the DS1820 will remain idle. If the master issues read time slots following this command, the DS1820 will output a zero on the bus as long as it is busy making a temperature conversion, it will return a one when the temperature conversion is complete.

WRITE SCRATCHPAD [4Eh]
This command writes to the scratchpad of the DS1820, starting at address 2. The next two bytes written will be saved in scratchpad memory, at address locations 2 and 3. Writing may be terminated at any point by issuing a reset.

To read a value from the 1-wire slave, or to transmit an instruction, the master/slave manipulates the DQ line for specific lengths of time, which will transmit/receive a one or a zero.

All of the instructions are made up of 8-bits. To Transmit an instruction across the 1-wire bus, the master must scan the 8-bits (*least significant bit first*) that make up the instruction then send either a one or a zero accordingly.

A ONE is transmitted by pulling the DQ line low for less than 15us, then released (*set to input*). As the write time-slot must be a minimum of 60us in length, the rest of the time-slot is padded out with a 60us delay.

A ZERO is transmitted by pulling the DQ line low for 60us, then released by configuring the pin as an input.

All write time-slots must have at least 1us between bit transmissions.

The subroutine below, writes an instruction across the 1-wire interface: -

```
DS_Write:
        For Bit_Cnt=1 to 8       ' Create a loop of 8-bits (BYTE)
        If Cmd.0=0 then          ' Check bit-0 of CMD
        Low DQ                   ' Write a 0-bit
        Pauseus 60               ' Send a low for more than 60us for a 0-bit
        DQ_DIR=1                 ' Release data pin (set to input for high)
        Else                     ' Else
        Low DQ                   ' Send a low for less than 15us for a 1-bit
@       Nop                      ' Delay 1us at 4mHz
        DQ_DIR=1                 ' Release the data pin (set to input for high)
        Pauseus 60               ' Use up the remaining time slot
        Endif
        Cmd=Cmd >> 1             ' Shift to the next bit
        Next                     ' Close the loop
        Return
```

Although the data from the DS1820 is in the form of a 9-bit word, the actual data length sent is 16-bits. Therefore, the master must read 16-bits from the slave (*most significant bit first*) and construct the word according to whether a one or a zero was received.

To Receive a bit from the slave, the master must pull the DQ line low for a minimum of 1us, then release the DQ line, which enables receive mode. The DS1820 (*which is now the transmitter*) pulls the DQ line low for ZERO, or high for ONE within a time-slot of 15us. As the read time-slot must be a minimum of 60us in length, the rest of the time-slot is padded out with a 60us delay.

All read time-slots must have at least 1us between bit receptions.

```
DS_Read:
        For Bit_Cnt=1 to 16     ' Create a loop of 16-bits (WORD)
        Temp=Temp >> 1          ' Shift down bits
        Temp.15=1               ' Preset read bit to 1
        Low DQ                  ' Start the time slot
@       nop                     ' Delay 1us at 4mHz
        DQ_DIR=1                ' Release data pin (set to input for high)
        If DQ=0 Then            ' Else
        Temp.15 = 0             ' Set the bit to 0
        Endif
        Pauseus 60             ' Use up the remaining time slot
        Next                    ' Close the loop
        Return
```

The above explanation and code is by no means only for the DS1820 device. All 1-wire devices operate on a similar protocol. Only the instructions for the specific device used will be different.

Measuring the temperature.

To read the temperature from a single DS1820 connected to the bus we can dispense with the 64-bit rom code.

Firstly, the 1-wire bus is initialised, then a skip rom instruction (*CCh*) is transmitted, followed by a convert instruction (*44h*).

The DS1820 is again initialised and another skip rom instruction is sent, followed by a read scratchpad instruction (*BEh*). The 16-bits of data may then be received from the DS1820.

We are only concerned with the first 9-bits of the 16-bits received from the DS1820, therefore, the last 7-bits may be disregarded.

The DS1820 has a resolution of 0.5°C; this is represented by the LSB (*bit-0*) of the 9-bits. A 1 signifies a 0.5° increment, while a 0 signifies an integer value.

Bits 1 to 7 are the temperature reading, bit-1 can be now thought of as the LSB of the temperature value.

Bit-8 is the sign bit, when this is 1 the result is a negative temperature and the first 8-bits are two's compliment (*1 becomes a 0 and vice-versa*).

Figure 7.1, illustrates the relationship of the 9-bits of data for both a positive and negative temperature.

Normal format for positive temperatures

MSB   LSB

| 0 | | 0 | 0 | 1 | 1 | 0 | 0 | 0 | | 1 |

= +24.5 °C

2's compliment format for negative temperatures

MSB   LSB

| 1 | | 1 | 1 | 0 | 0 | 1 | 1 | 1 | | 0 |

= -24.5 °C
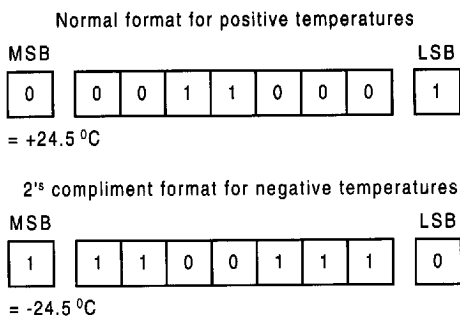
Figure 7.1. 9-bit data format.

Program **DS1820.BAS**, displays, the temperature of a single DS1820 connected to PortB.0. Figure 7.2 show the connections to the PIC.

The program is centred around three subroutines; these are **DS_INIT**, **DS_READ**, and **DS_WRITE**.

The first to be called is **DS_INIT**, this subroutine initialises the 1-wire bus and checks for a presence from the DS1820. If no device was detected then the flag, **DS_VALID** will return holding 0, else it will return holding 1 if all is well.

Four instructions are then transmitted by using the **DS_WRITE** subroutine. The instruction to send is first loaded into the variable **CMD**. The subroutine scans the **CMD** variable by examining bit-0, if it is clear then a 0 is transmitted on the bus, and if it is set then a 1 is transmitted. **CMD** is then shifted right one place, and the same process is carried out eight times to transmit the 8-bit byte (*least significant bit first*). After the four instructions have been transmitted, the subroutine **DS_READ** is called. This reads the incoming bit stream (*most significant bit first*) and places them into the 16-bit variable **TEMP**. This is accomplished by reading a bit from the DS1820 and placing it into bit-15 of **TEMP**, the variable **TEMP** is then shifted right 1 place. If the bit read is a 0 then bit-15 will be cleared, and if the bit read is a 1 then bit-15 will be set. This is carried out 16 times to build up the 16-bit result.

We now have our 16-bit result from the DS1820, however, we are only interested in the first 9-bits. Firstly, bit-8 is examined, if it is set (*1*) then a negative temperature has been measured and the flag **NEGATIVE** is set to indicate this fact. This also indicates that the first 8-bits are two's compliment. Therefore, the lowbyte of the variable **TEMP** must be XORed with 255, to convert it back to normal format (*xoring with a 1 has the effect of reversing the bit, 1 becomes 0 and vice-versa*).

Regardless whether a positive or negative result was received, the variable **TEMP** now holds the 7-bits of temperature and the 0.5°C increment (*bit-0*). To convert this into a format we can use, the lowbyte of **TEMP** is shifted right 1 place and the result is placed into the variable **DEG**, this now holds the correct 7-bit temperature reading (*0-127*). In order to place the 0.5 increment, the result held in **DEG** has to be scaled up by a factor of 10. This will now give us a temperature value of between 0 and 1270.

To include the 0.5 increment value in our final result, we examine bit-0 of **TEMP** (*the original value was not altered by shifting it right*). And multiply its result by 5, if bit-0 was clear then the product will be 0 (*0*5*), however, if the bit was set then the product will be 5 (*1*5*). This product is then added to the value held in **DEG**.

Upon the subroutines return, one variable and a flag have been loaded, **DEG**, and **NEGATIVE**. This will allow us to display a minus sign if the temperature is negative, as well as inform the program as to the actual temperature.

To display the minus sign, the flag, **NEGATIVE** is examined, and depending on its value, the variable **NEG_POS** is loaded with the character, '-' or space.

The final display is split into four parts within the same debug command. Firstly, the variable **NEG_POS** is displayed, this hold a minus sign or a space, depending on the value of **NEGATIVE**. Then the value left of the decimal point is displayed, by dividing the variable **DEG** by 10. The value to the right of the decimal point is displayed by calculating the remainder of **DEG** divided by 10 (*//*). And finally the degrees sign is displayed, this was setup at the beginning of the program.
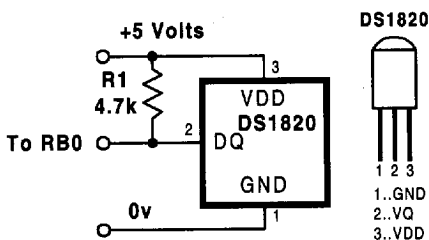

Figure 7.2. DS1820 configuration.

Experimenting with the PicBasic Pro Compiler

Interfacing with the LM35 temperature sensor

Interfacing to the National Semiconductors LM35 is totally different from the DS1820, and is simpler to use in many respects. The LM35 was designed with analogue interfacing in mind, therefore it outputs a voltage that is proportional to the temperature (*in °C*) in 10mV steps. For example, if the LM35's output voltage is 0.22V, then the temperature is 22°C. The maximum temperature that the LM35 will measure safely is 125°C which will produce a voltage of 1.25V.

Program **LM35_87X.BAS** uses a 16F876 (*or any other pic with an on-board ADC*) to display a temperature between 0 and 125°C and its corresponding voltage, on a serial LCD connected to PortC.6.

The ADCIN command is setup (*as described in the analogue to digital section*) to convert a voltage presented to its AN0 input (*PortA.0*). The temperature is then displayed by moving the decimal point one place to the right.

```
        ADCON1= %10001110              ' Configure for AN0 as analogue
                                       ' input with right justified result
Again:
        ADCIN 0,AD_Res                 ' Do the ADC conversion
        Debug I,Line1,#(AD_Res/100),".",#(AD_Result//100),4,"C "
                                       ' Display the temperature
        Debug I,Line2,#(AD_Res/1000),".",#(AD_Result//1000)," Volts  "
                                       ' Display the voltage
        Pause 200                      ' A small delay
        Goto Again                     ' Do it forever
```

Figure 7.3 shows the connections to the PIC.
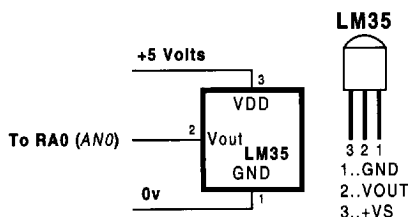
Figure 7.3. LM35 configuration.

If a PIC is used that does not have an on-board ADC, such as the PIC16F84, then an external device must be employed. This is a perfect application for the extra simple MAX187 12-bit ADC. Figure 7.4 shows the circuit for such a hook-up.
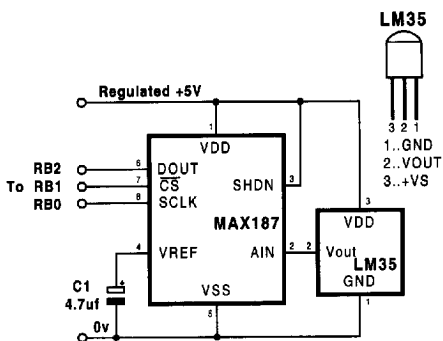
Figure 7.4. LM35 connections to the MAX187 ADC.

The program **MAX_TEMP.BAS** is used for this demonstration. The program simply calls the **MAX_IN** subroutine to acquire a voltage sample from the MAX187.

```
MAX_In:
      Max_Val=0
      Low Cs                                    ' Activate the MAX187
      Shiftin Dout,Sclk,Msbpost,[Max_Val\12] ' Clock in 12-bits
      High Cs                                   ' Deactivate the MAX187
      Return                                    ' Exit the subroutine
```

The result held in the variable **MAX_VAL** is divided by 10 to produce the degrees and the remainder is also divided by 10 to produce the decigrees.

Debug I,Line2,dec2 (Max_Val/10),".",dec1 (Max_Val//10),4,"C"

There is no need to quantasize the result from the MAX187, as the voltage from the LM35 will not exceed 1.25V. Which is the equivalent to 125°C.

Section-8

Experimenting
with
Robotics

Proximity detection principals.
Single direction infrared proximity detector.
Infrared proximity detector with distance gauge.
Directional infrared proximity detector.
Ultrasonic proximity detector.
Driving a DC motor using an H-Bridge.
Driving a DC motor using the L293D.

Proximity detection principals

Detecting a collision on a robot is normally accomplished by sensing when a switch has been triggered by bumping into something, however, avoiding the collision altogether is a much more desirable goal. There are two main ways of providing proximity detection for the purpose of avoiding collisions, these are light and sound. Infrared light and ultrasonic sound to be exact.

First, we shall look at two possible ways of using infrared light as a proximity detector. The first is a single direction device, while the second is a directional device (*left, right, and centre*).

Proximity detection using infrared light is possible due to the fact that light always travels in a straight line, and bounces of just about everything (*to a greater or lesser extent*). We can use this fact to our advantage by transmitting a pulse of light then looking for its reflection. If there is no reflection then nothing must be in front of the detector.

We shall be using the same infrared detector that was used in the remote control section, namely an SFH506-38. This is sensitive to infrared light modulated at 38kHz. As with the infrared remote control experiments, modulated light is used to eliminate unwanted ambient light, caused by the sun, or man made sources such as fluorescent lighting. The infrared source for these experiments is a 5mm infrared LED, again the same type used in the infrared remote control experiments.

We shall also look at detection using ultrasonic sound. As with infrared light, ultrasound is also modulated but this time at 40kHz in an attempt to eliminate background noises. But unlike light, sound travels much slower, therefore, we are also able to sense the distance to the object that has been detected.

Single direction infrared proximity detector.

Figure 8.1 shows the circuit for the infrared proximity detector (*IRPD*).

Although the PIC is capable of sourcing currents of up to 20mA, a single transistor buffer will increase the range of the IRPD two-fold.
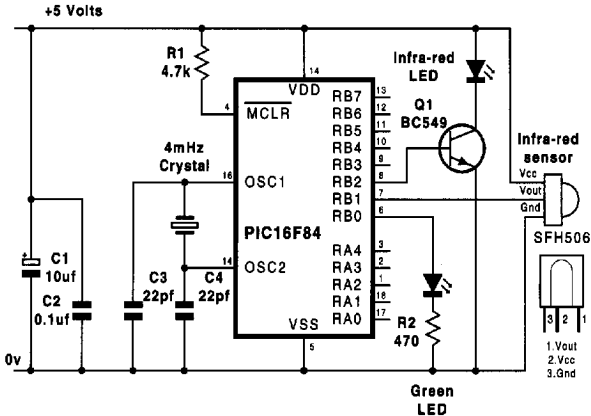
Figure 8.1. Infrared proximity detector.

A requirement in the final product is that the LED must not leak any light from its sides, which would trigger the detector constantly. To help alleviate this, heatshrink sleeving is placed over the LED with only the lens at the front left clear, shown in figure 8.2.
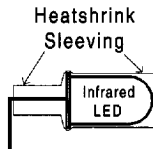
Figure 8.2. Heatshrink sleeving over the infrared LED.

Another consideration when building the final project is the positioning of the detector and LED. They should obviously be pointing in the same direction, however, the LED must be slightly forward of the detector or the light will penetrate through the back of it. In the prototype, the IR detector was painted black on all sides, leaving only the front lens exposed. Figure 8.3 shows the arrangement used.

Experimenting with the PicBasic Pro Compiler
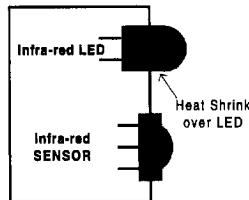
Figure 8.3. Arrangement of detector and LED.

Program **IR_PROX.BAS** uses the circuit in figure 8.1 to detect an object up to 24 inches in front. It transmits a pulse of modulated light for 400us then waits for a reflection. In order to eliminate false reflections the process is carried out ten times and only when ten reflections are received is the green LED lit, which indicates that an object has been positively detected. The program is based around the **PING** subroutine, this sends out the 38kHz modulated infrared light. The method for modulating the LED is explained in the remote control section.

A for-next loop of 10 is set up and the **PING** subroutine is called. PortB.1 is then examined (*IR detector*), if it's low then a reflection has been detected and the variable **HITS** is incremented. If PortB.1 is high then there has been no reflection and **HITS** is left alone.

After the ten transmissions have finished, the value of **HITS** is examined. If ten reflections were detected the variable **HITS** will hold the value 10, and the green LED is illuminated to signify a positive contact in front.

If you find that the IRPD is over sensitive and is detecting distant objects or the LED is constantly illuminated, the frequency of the modulation may be increased or decreased. This is accomplished by increasing or decreasing the number of NOP's in the **PING** subroutine. Removing NOP's will increase the frequency of the modulation, and adding NOP's will decrease the frequency. This will have the effect of lowering the sensitivity of the detector.

Alternatively, the infrared LED may be attached directly to the PIC, and Q1 may be discarded.

Experimenting with the PicBasic Pro Compiler

Infrared proximity detector with distance gauge.

If you built the single direction IRPD you will have noticed that at the periphery of its detection range the LED flashes. This is because the further away the object is from the IR detector the less likely that 10 reflections will be counted. We can put this observation to good use.

By counting how many reflections have been received we can get an approximation of distance. For example, if all 10 reflections were received then the object must be close to the detector, however, if only 5 reflections of the possible 10 were detected, the object must be a little further away. For practical use 10 samples is not enough, therefore, the program **DIS_PROX.BAS** takes 30 samples and increments the variable **HITS** when a reflection is detected.

If **HITS** has the value of 10, then only 10 reflections were detected from 30 samples taken, which is just on the periphery of the IRPD's limit. The green LED is illuminated to indicate a distant object was detected.

If **HITS** has the value of 20 from a possible 30 samples taken, then the object must be a little closer and the yellow LED is illuminated.

If **HITS** has the value of 30 from a possible 30 samples, then the object must be close to the detector, and the red LED is illuminated.

Figure 8.4 shows the circuit layout for this method.
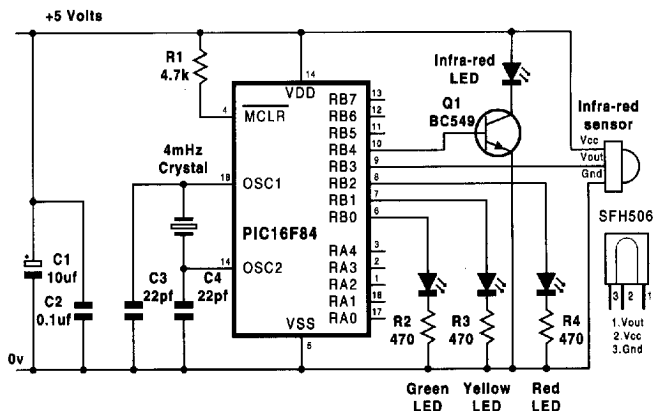
Figure 8.4. IRPD with distance gauge.

Directional infrared proximity detector.

The Directional IRPD uses the same method as the previous experiments, transmitting a pulse of light and detecting a reflection. However, it is capable of determining whether an object is to the left, right, or centre.

Two infrared LEDs are placed either side of the infrared detector, pointing away from it at an angle of approx 30 to 45 degrees. Figure 8.4 shows the arrangement.
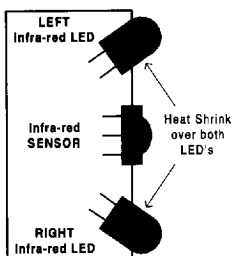
Figure 8.4. LED and detector arrangement for directional IRPD.

Each infrared LED is pulsed in turn and a reflection is detected. If a reflection is detected when the left LED was pulsed then an object is to the left. If a reflection is detected when the right LED was pulsed then an object is to the right. However, if a reflection was detected for both left and right then the object must be in front. Figure 8.5 shows the circuit for the directional IRPD.
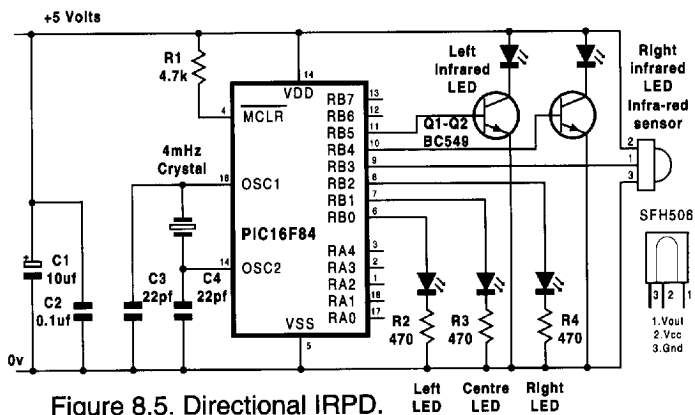
Figure 8.5. Directional IRPD.

Experimenting with the PicBasic Pro Compiler

The program **LR_PROX.BAS** uses the same method as the last two experiments. However, there are now two infrared pulsing subroutines, one for the left LED, **PING_LEFT**, and one for the right, **PING_RIGHT**.

Each LED is pulsed ten times by calling each **PING** subroutine in turn and the amount of reflections from each are placed in the variables **HITS_LEFT**, and **HITS_RIGHT**.

The two variables are then examined, if they are both greater than seven then both LEDs produced a reflection 7 or more times, which means there must be an object in front of both of them. So the left and right LEDs are extinguished and the centre led is illuminated.

Next, the variable **HITS_LEFT** is examined; if this holds a value of ten then the left LED produced a reflection 10 times out of 10. Which means there must be an object to the left of the detector. So the right and centre LEDs are extinguished and the left led is illuminated.

Finally the variable **HITS_RIGHT** is examined, if this holds a value of ten then the right LED produced a reflection 10 times out of 10. Which means there must be an object to the right of the detector. So the left and centre LEDs are extinguished and the right led is illuminated.

The placement of the LEDs is even more critical in this application as there are now two infrared light sources. Care must be taken to ensure that no light leaks from either LED, all the light should be directed forwards.

If you find the LED is constantly illuminated, the frequency of the modulation may be increased or decreased. This is accomplished by increasing or decreasing the number of NOP's in the **PING** subroutines. Removing NOP's will increase the frequency of the modulation, and adding NOP's will decrease the frequency. This will have the effect of lowering the sensitivity of the detector.

Alternatively, the infrared LED may be attached directly to the PIC, and Q1 and Q2 may be discarded.

Ultrasonic proximity detector.

Using ultrasonic sound instead of infrared light for proximity detection is the same in many respects. However, as sound travels much slower than light (*approximately 0.3 m/ms or 1ft/ms, and 0.3m/ns or 1ft/ns respectively*), we can us a method called *time of flight* (*TOF*) to judge the distance of an object as well as detect its presence. Time of flight is the time taken from the transmitter sending its ping to the receiver detecting the echo.

To send and receive the ultrasonic signals we use two transducers, the transmit transducer (*TX*) is a form of speaker whose resonant frequency is 40kHz. The receiving transducer (*RX*) is a form of microphone with the same resonant frequency. Modulating the frequency of the sound at 40kHz has the same effect as modulating the infrared signals, that of ambient noise elimination (*almost*).

Figure 8.7 shows the circuit for the ultrasonic proximity detector. Unlike the infrared experiments, there is no ready-made detector for sound that will convert its signal into a TTL voltage. This has to be accomplished by an amplifier, an op-amp in this case.

The TX transducer is connected to PortA.0 and PortA.1 of the PIC, This acts as a form of push-pull drive, one pin alternates from high to low, while the other pin alternates from low to high. This method achieves greater drive to the transducer. Any object in the path of the signal will cause a reflection. The reflected signal is at a significantly lower amplitude compared to the original transmitted signal, therefore we need to amplify it by approximately 100 times, this is set by R4 and R5 of the op-amp IC1. Capacitor R7 feeds a transistor (*Q1*), whose purpose is to provide TTL level pulses to the PIC. VR1 and R6 adjust the bias on the base of Q1, which determines the overall sensitivity of the circuit. The transistor's normal state is high (*5V*) but is pulled low when a suitably strong echo has been detected.

Initially, the bias level on the base of Q1 should be adjusted to 0.4V. This will give us a sensitivity of approximately two feet. Any more sensitive and we will increase the chance of detecting stray reflections.

Reducing the bias level will decrease the sensitivity of the circuit.

The program **SON_PROX.BAS** transmits a pulse of 40kHz modulated sound for a duration of 600us using the **PING** subroutine. As the transducer has to be switched from high to low extremely rapidly for the push-pull effect to work, assembly code has had to be used. The principals of this subroutine are very similar to the infrared remote control experiments.

After the **PING** subroutine has sent out its pulse, we must look for an echo on PortA.2. If we were to examine PortA.2 and continue with the code, we would miss the signal, as it wouldn't have reached the receiver yet. Remember, sound travels a lot slower than light. We must therefore give the receiver time to detect the echo.

This is accomplished by creating a loop counting up to 255; within this loop we continually examine PortA.2 for a low, which will signify that an echo has been heard. If an echo has been heard the loop is exited, and the value of the loop variable (*E_TIME*) now contains a number representing a distance, the further away the object, the closer it will be to 255. If an echo was not heard then the loop exits normally and the **E_TIME** variable is cleared.

This has given us a means of detecting and gauging the distance of an object, however, to try and eliminate false reflections we use the same principal that was used in the infrared proximity detectors. We sample the incoming echo ten times and each time an echo is heard the variable **HITS** is incremented. If, at the end of ten samples **HITS** contains the value 10, there has been a positive contact with an object, and the green LED is illuminated. A serial LCD connected to PortB.0 displays the variable **E_TIME**, which is a representation of the distance.

Each time the transmitter sends out a ping, the receiver physically vibrates (*rings*) in sympathy. This ringing can cause the receiving software to see a false reflection immediately after the ping. In order to combat this problem the receiver transducer must be padded. This was accomplished in the prototype by placing a strip of felt around the body of the transducer, and also on the bottom where the connecting wires protrude. Figure 8.6 illustrates this.

Ultrasonic proximity detector
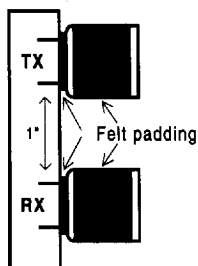
Figure 8.6. Positioning and cushioning of the transducers.
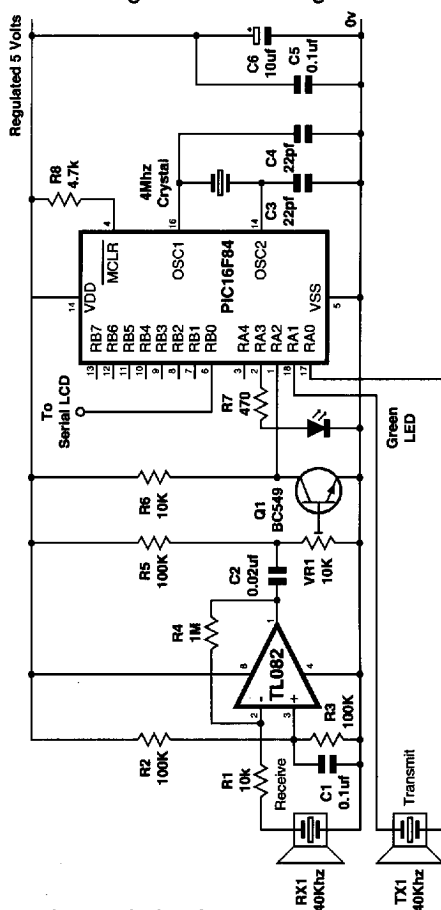
Figure 8.7. Ultrasonic proximity detector.

Program – H_BRIDGE.BAS

Driving a DC motor using an H-Bridge.

For this experiment, the motor used was the DC type supplied with the LEGO ROBOTICS SYSTEM. These are 9V types, which draw a few hundred milliAmps. However, any type of motor may be used as long as the voltage and current handling limits of the circuits or motors are not exceeded.

To control the direction of a motor with logic levels presented from the PIC, we use an H-bridge circuit. Figure 8.8 shows a typical layout. It's called an H-bridge, because it resembles the letter H in its configuration.
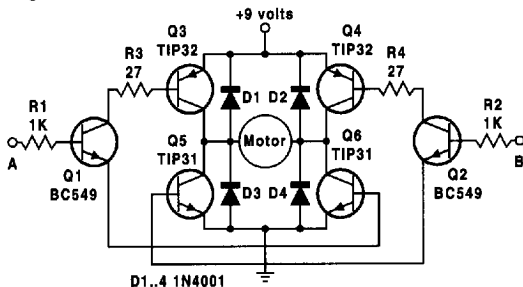
Figure 8.8. Discrete H-Bridge.

The circuit is configured in such a way that only two transistors are conducting at any one time. When transistors Q3 and Q6 are on, the motor spins in one direction. When transistors Q4 and Q5 are on, the motor spins in the opposite direction. When all the transistors are off then the motor remains motionless. Transistors Q1 and Q2 act as buffers to the PIC, therefore allowing a small current to control four larger current transistors. D1 to D4 are *flyback suppression* diodes and are in place to protect the transistors from any high voltage spikes created by the motor's windings.

Q3 to Q6 should be chosen to suit the motor used, in this case TIPs are more than adequate. If a larger motor is used then transistors with a larger current capability must be used.

To control the direction of the motor two pins are required from the PIC. These connect to A and B of the H-bridge. When either one of these lines is brought high while the other is pulled low then a different direction is chosen. If both are pulled low then the motor remains still.

Experimenting with the PicBasic Pro Compiler

The direction of the motor depends on which way it is inserted into the circuit. Connecting its positive terminal to Q4 and Q6 will have a different direction than connecting it to Q3 and Q5.

Note. Lines A and B should never be both brought high for any length of time, as this will turn on all four transistors, resulting in a near short circuit. However, we can use this to our advantage, when a motor's terminals are shorted together the motor's shaft is hard to turn by hand. Using this principal we can set Lines A and B of the H-bridge high for a few milliseconds (*ms*) to act like a brake and stop the motor in its tracks, instead of just slowing to a stop.

Program **H_BRIDGE.BAS** demonstrates the simplicity of controlling the H-bridge circuit of figure 8.8. Line-A of the H-bridge is connected to PortB.0 of the PIC, and Line-B is connected to PortB.1. The program cycles through, turning the motor first one way and stopping then turning it in the opposite direction. The direction it should be turning is displayed on a serial LCD connected to PortA.0.

To demonstrate the braking method, subroutine **BRAKE** is called just before a stop. This brings both Line A and B high for 100ms, just enough time for the braking effect to work but not enough time for any damage to be caused to the transistors.

When controlling motors, or indeed any heavy load. A large capacitor should be placed across the PIC's supply lines. A 3300uF is normally sufficient. This help smooth out any spikes caused by the motor being initially activated.

Driving a DC motor using the L293D.

The SGS-Thompson L293D is the robot enthusiasts favourite motor driver. The device contains four push pull drivers as well as their flyback protection diodes. Each driver is capable of producing 600mA continuous output current.

Figure 8.9 shows the internal configuration of one of these devices.
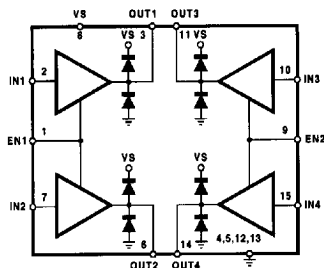
Figure 8.9. L293D internals.

The most common configuration for the L293D is as two separate H-bridges. This allows the device to supply up to 1Amp to the motor. If such high currents are being implemented a heatsink must be used.

Figure 8.10 shows an L293D being used in the H-bridge configuration. The IN1 and IN2 pins act like the A and B lines of the discrete H-bridge.

IN1	IN2	Motor Direction
1	0	Forward
0	1	Reverse
0	0	Stopped (*Brake applied to motor*)
1	1	Stopped (should be avoided)

The EN1 pin is an enable line, when this is pulled low the output voltage to the motor is disengaged.

To allow the device to be controlled by low voltage (*TTL*) levels, a separate logic voltage may be applied to the VSS pin. While the motor's supply voltage, which is usually a lot higher, is connected to the VS pin.

Driving a DC motor using the L293D
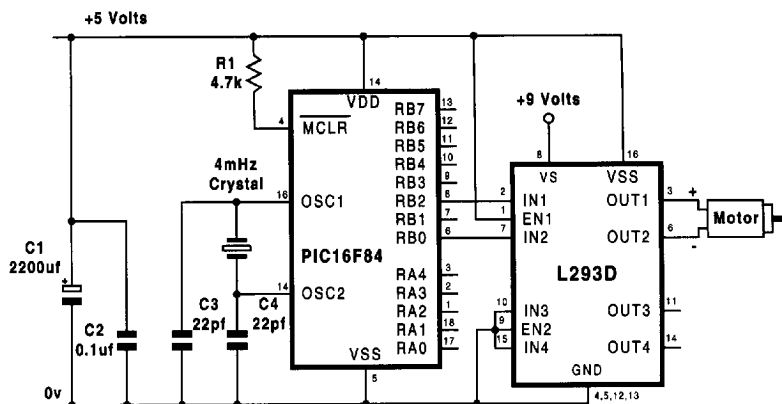
Figure 8.10. L293D H-Bridge motor control.

Program **L293D.BAS** demonstrates control of the L293D. The program cycles through, turning the motor first one way and stopping then turning it in the opposite direction. The direction it should be turning is displayed on a serial LCD connected to PortA.0.

The datasheets for all the parts used in this section can be found on the accompanying CDROM.

Section-9

Experimenting with Audio Control Devices

Adding a voice to the PIC with the ISD1416.
Recording and playing back multiple messages.
Allowing the PIC to audibly count.
Digital volume control using the AD840X.
Controlling the gain of an op-amp.
Digital active bass and treble controls.

Adding a voice to the PIC with the ISD1416.

Imagine having your latest digital thermometer tell you the temperature, or the robot you have just built actually tell you that it needs its battery recharged. And what's more, it can tell to you in your own voice!

This is all possible thanks to a new series of devices from ISD; called *Chipcorders*. A range of devices are available that allow more than 20 seconds of speech to be recorded onto the chip, and played back complete, or several smaller messages may be recorded and selectively played back. The device we shall be using is the ISD1416, which will allow a complete message of 16 seconds or several smaller messages.

The ISD1416 may also be used as a stand-alone project for use as a memo pad. Figure 9.1 shows the circuit for just this type of operation.
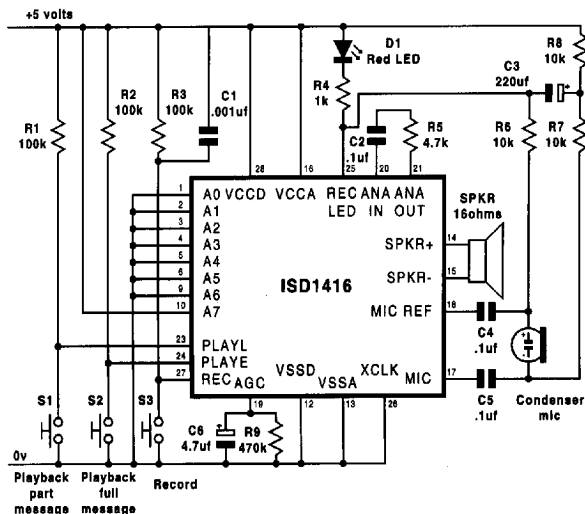
Figure 9.1. ISD1416 memo pad.

In the circuit above, a recording is made by pressing S3. The LED will illuminate to indicate record mode is operational. When the message is complete; releasing S1 will disengage record mode. To listen to the message S1 or S2 may be used. S1 will play the message as long as it remains pressed. S3 will play the message to its completion with a momentary press and pulse the LED when it is finished.

Once the message is recoded onto the chip it will remain, even when the power is removed. According to the datasheet it will stay recorded for 100 years. (*how do they know?*). We can use a single message as an audio indicator or warning by applying a pulse to the PLAYE pin instead of using a push switch. The pulse must have a high to low transition for the ISD to detect it. This is easily accomplished by the lines of code below: -

PLAYE_PIN   Var   PortA.0

*   High PLAYE_PIN   ' Set the line initially to high*
@ Nop   ' A 1us delay
*   Low   PLAYE_PIN   ' Bring the line low*

Recording and playing back multiple messages.

To record and playback multiple messages; the address lines of the ISD must be used (A0..A7). Figure 9.2 shows the connection of a DIL switch, which will allow different portions of the ISD's non-volatile RAM to be accessed. The rest of the circuit is identical to figure 9.1.
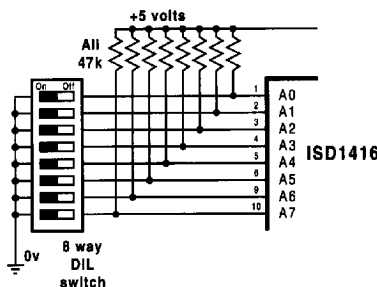
Figure 9.2. DIL switch connection.

The RAM within the ISD device may be thought of as a piece of audiotape, changing the value applied to the address lines A0..A7 is likened to placing the audio head anywhere on the tape. Placing the binary value %0 on the address lines may be thought of as placing the audio head at the beginning of the tape. The 16 seconds of recording time may be split into 160 segments; each segment is 100ms in length. This is like moving the head every few inches along the tape. This means that the value placed on the address lines has a range of 0 to 160.

Experimenting with the PicBasic Pro Compiler

Address lines A6 and A7 have a dual purpose. When they are both brought high then a system named *operational mode* is enabled, which allows looping of the message as well as several other functions. Operational mode has no relevance to our design, therefore, we will not discuss it. If you wish to find more about operational mode, there are very comprehensive datasheets on the accompanying CDROM for most of the ISD range of devices.

As long as an address above 160 is not chosen, operational mode will not be enabled.

We will now look at a method of recording and playing back four separate messages. Each message will have a maximum length of four seconds. This doesn't seem a lot, but you will be surprised at how much can be said in such a small amount of time.

To record the first message, a value of 0 must be placed on the address lines. The DIL switch should be setup as in figure 9.3a. Now press the record button (*S1*) until the message is spoken. Pressing the play button will play back the freshly recited message. Each consecutive message must have the DIL switch positioned according to the remaining three settings of figure 9.3. To play back each message the same value must be placed on the address lines.
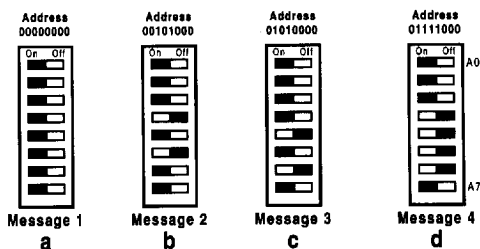
Figure 9.3. DIL switch configuration for messages.

Now that we have our four distinct messages recorded at addresss %00000000 (*0*), %00101000 (*40*), %01010000 (*80*), and %01111000 (*120*) the ISD chip may be hooked up to the PIC. This is a simpler layout than the recording version as the microphone section is not required. Figure 9.4 shows the circuit for this.

Adding a voice to the PIC with the ISD1416

Figure 9.4. ISD1416 connections to the PIC.

Program **4_MESGE.BAS** demonstrates playing back the four messages that have been recorded. The PLAYE line is not used in this demonstration therefore; it is disconnected by making PortA.2 an input allowing R3 to keeps it pulled high. The program itself is very primitive, all it does is load the corresponding message address's onto PortB and call the **SAYIT** subroutine.

The **SAYIT** subroutine waits 50ms before enabling the ISD chip. This gives it time to process the contents on the address line. The PLAYL line is then held high and a delay of 1us is implemented before the line is pulled low. This will trigger the ISD into playing the corresponding message. To establish when the message has finished, the REC_LED line is polled. This pulses low when the message has ended.

The delays were found necessary in order for the ISD chip to play the proper message and were found by trial and error, smaller delays may work just as well.

If more messages are required then the same method applies. However, the message lengths will need to be smaller.

Allowing the PIC to audibly count

We can go one further and make the ISD chip speak numbers or even count. First, we must record multiple separate messages. These will be the digits 0 to 9 and also the word 'point'. If this program is to be used for a digital thermometer then the word 'degrees' must be also be recorded.

As an example we will assume a talking digital thermometer is being implemented. Therefore, 12 messages need to be recorded. First we must calculate the length of each message. This is accomplished by dividing the maximum length (*in seconds*) that the chip will allow (*16 in our case*) by the number of messages required: -

$$16 / 12 = 1.3$$

This gives us a length of 1.3 seconds per message. To configure this as an address to present to the ISD chip, simply multiply the length of the message by ten, which will give us 13. Then each message's address is a multiple of this number plus 1. *i.e.*

Message one address = 0
Message two address = 14   *(which is equal to (0 + 13)+1*
Message three address = 28   *(which is equal to (14+13)+1*
Message four address = 42   *(which is equal to (28+13)+1*

The value one needs to be added to the message address to avoid the end of message marker that the ISD chip places (*not surprisingly*) at the end of each message. When the end of message marker is reached, the REC_LED line is pulsed low. Without this pulse, the PIC will keep on polling for it and become stuck in an endless loop.

Table 9.1 shows the values to place on the address lines for each of the twelve messages required for a digital thermometer example. Or any program that requires 12 messages to be spoken.

Message No#	Message Spoken	Address of message	Dec
1	ZERO	00000000	0
2	ONE	00001110	14
3	TWO	00011100	28
4	THREE	00101010	42
5	FOUR	00111000	56
6	FIVE	01000110	70
7	SIX	01010100	84
8	SEVEN	01100010	98
9	EIGHT	01110000	112
10	NINE	01111110	126
11	POINT	10001100	140
12	DEGREES	10011010	154

Table 9.1. Address values for the demonstration program.

Using the 12 messages that have been previously recorded; the ISD chip is now able to speak any digit from 0 to 9. With the ability to speak the digits; the next step was to build up the digits into a counting program. Program **ISD_CNT.BAS** does just that. It is centred around the subroutine **SAYIT**, which takes the 16-bit value held in **S_NUM** and speaks the individual digits of that value.

The **SAYIT** subroutine works like this. A loop is created to extract the individual digits from the 16-bit value; using the DIG operand. The variable **SN** now holds the individual digit. We do not wish to hear the leading zeroes of each number being spoken, therefore leading zero suppression is accomplished by a group of *if-thens*. A lookup table is then used to extract the address for the specific number to be spoken. And this value is placed onto PortB. The **PLAY** subroutine is than called which triggers the ISD1416.

As a demonstration of the capabilities of this program the words 'POINT' and 'DEGREES' are also spoken. The word 'POINT' is spoken by placing the address for the 11th message onto PortB and calling the **PLAY** subroutine. The word 'DEGREES' is spoken in a similar manner, except the address for the 12th message is placed onto PortB before the **PLAY** subroutine is called.

Digital Volume control using the AD840X

Digital variable resistors were covered in detail in the digital to analogue section. However, they are so versatile and capable of extremely low noise operation that it was inevitable that they would be used in audio equipment. Figure 9.5 shows one of the obvious applications for a digital resistor, that of a volume control.
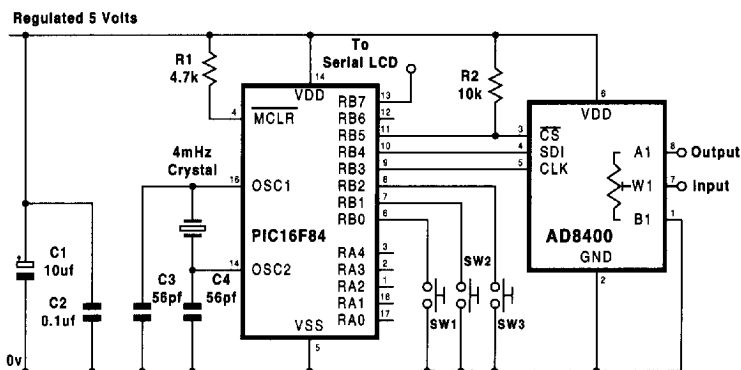
Figure 9.5. Digital volume control.

Program **AD8400.BAS** uses the circuit in figure 9.5. The A1 pin of an AD8400 may be connected to the input of an amplifier and the W1 pin may be connected directly to a microphone or the output from a pre-amp. SW1 controls Volume up, and SW2 controls Volume down, SW3 stores the current volume level in the PIC's internal eeprom. The programs main subroutine called **POTOUT**, controls the AD8400 via its 3-wire interface. Instead of selecting a specific resistance to output, the subroutine calculates the percentage of the resistance. This is necessary because of the different resistance types available (*i.e. 1kΩ, 10kΩ, 50kΩ, and 100kΩ*). There is no real need to know the specific resistance, as we know that %90 of a 50kΩ resistance is 45kΩ, and %90 of a 10kΩ resistance is 9kΩ.

We know that the digital pots have a resolution of 256 (*0-255*). So to calculate the percentage we just divide by 100. However with the limitations of the math routines in the compiler, the values had to be scaled up and then down again. Like this: -

P_Output=(Percent*255)/100

The variable **PERCENT** holds a value (*not surprisingly*) between 0 to 100. The variable **P_OUTPUT** holds the data byte to be sent to the DCP. When using the AD8400, the address bits (*bit-8 and bit-9*) must both contain zeroes. This is achieved by simply clearing both bits: -

P_Output.8 = 0
P_Output.9 = 0

The AD8400 is enabled by bringing the CS line low and the 10-bit word is shifted out, with the Most Significant Bit sent first: -

SHIFTOUT SDI , CLK , Msbfirst , [P_Output \ 10]

The CS line is brought high to disable the chip, and the subroutine is exited.

Controlling the gain of an op-amp

The second demonstration using the AD8400, shown in figure 9.6. Uses the two terminal or REOSTAT mode, the gain of an inverted op-amp amplifier is controlled by the DCP. The digital pot is connected between the inverting input and the output of the op-amp. A 10kΩ part was used in this demonstration but higher gains could be achieved by using a 100kΩ part. When the DCP is at %0 (50Ω) there is less than unity gain, when the DCP is at %10 (1kΩ) there is unity gain and when the DCP is at %100 (10kΩ) there is a gain of 10. The 3-wire interface connects to the PIC as in figure 9.5. Switches SW1 and SW2 control the gain, SW3 stores the current gain level in the PIC's internal eeprom.

The Program for this demonstration is **AD8400.BAS**.
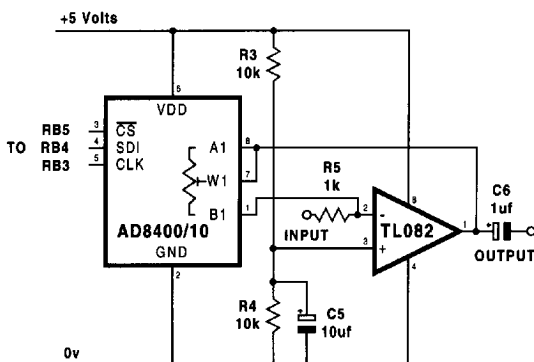
Figure 9.6. Op-amp gain control.

The versatility of these devices is never ending, virtually anything that uses a mechanical potentiometer can be controlled with one of these remarkable IC's.

Digital active bass and treble controls

Figure 9.8 illustrates the use of the dual digital pot (AD8402) as a mono bass and treble controller. The circuit looks more complicated than it actually is, figure 9.7 shows a simplified layout of the same circuit.
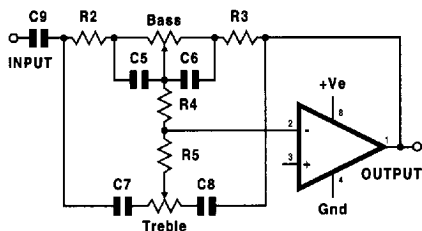
Figure 9.7. Simplified bass and treble.

It's a conventional tone control found in most audio amplifiers, only one channel is shown. If stereo operation is required an AD8403 will have to be used as it contains four RDAC's.

The bass is adjusted by RDAC1 (*A1, B1, and W1*), while the treble is adjusted by RDAC2 (*A2, B2, and W2*). The four switches (*SW1..4*) attached to the lower 4-bits of PortB control bass up or down, and treble up or down, and are displayed on a serial LCD attached to PortB.7. Switches 1 and 2 control Bass while Switches 3 and 4 control Treble.

Program **AD8402.BAS** is for use with figure 9.8. It is centred around the subroutine **POTOUT**, this subroutine outputs the 10-bit word to an AD8400, AD8402, or AD8403 digital pot. The internal RDAC of choice (*1..4*) is loaded into the variable **RDAC**, and the percentage of the resistance is loaded into the variable **PERCENT**. For example, if the bass, which is controlled by RDAC1 is to be increased to %90, variable **RDAC** is loaded with 1, and **PERCENT** is loaded with 90 then the **POTOUT** subroutine is called: -

```
RDAC = 1           ' Point to RDAC1
PERCENT = 90       ' %90 of the RDAC's resistance
Gosub POTOUT       ' Shift out PERCENT to RDAC1
```

Experimenting with the PicBasic Pro Compiler

The rest of the program is essentially a series of *if-then's* that scan the lower 4-bits of PortB to see which switch has been pressed. And then act upon whichever switch is operated.
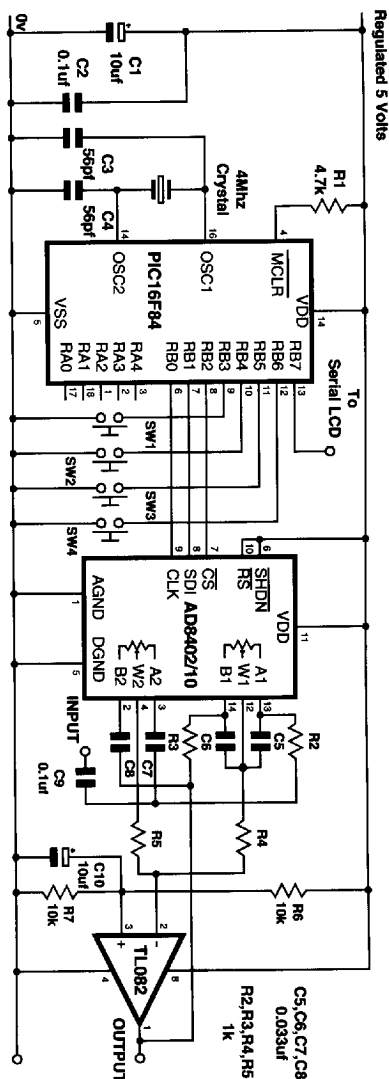
Figure 9.8. Active digital Bass and Treble control.

Section-10

Programming Techniques

Integrating Assembly language into your programs.
Declaring Variables for use with Assembler.
Passing parameters using the DEFINE statement.
Using INCLUDE files to tidy up your code.
Waking the PIC from SLEEP.
A brief introduction to Hardware INTERRUPTS.
Using the ON INTERRUPT command.

Experimenting with the PicBasic Pro Compiler

Integrating Assembly language into your programs

This may come as a blow to any die-hard BASIC programmers out there, but assembly language subroutines are occasionally unavoidable. Especially when time-critical or ultra efficient code is required. Not everyone agrees on this, and I would be more than happy to be proved wrong. However, until such time, I feel duty bound to try and show you how to incorporate assembler routines seamlessly and painlessly into your BASIC code.

If you do not use assembly language at all, then you may wish to skip the next few pages. However, I urge you to gain even a rudimentary understanding of assembler. You will achieve a greater insight into how the PIC functions at its base level, and it will also allow information to be gleaned from Microchip's many datasheets and app-notes (sometimes!). This will ultimately lead to better compiler programs being written.

The ability to place in-line assembler into your code can be a powerful tool if used appropriately, however, it can also be your worst nightmare if a bug or glitch should arise. Therefore, it is always advisable to seek a standard BASIC approach to solving a particular coding problem, if at all possible. Some of the experiments in this book use assembler subroutines out of necessity to achieve a certain goal. Prime examples of this are the MSSP, eeprom subroutines, **EREAD** and **EWRITE**, discussed in section-3. The BASIC coded version is 204 Bytes in length, while the assembler coded version, which has exactly the same function and is transparent to the programmer, is only 116 Bytes. Surely, the saving of 88 Bytes of precious ROM is worth the use of assembler.

A major consideration when using assembler subroutines are bank boundary conflicts. All the 14-bit core devices use ROM boundaries of 2k (0-2048). The problem with crossing these boundaries is that, the assembler's GOTO and CALL instructions only supply 11-bits of the 13-bits required by the *program counter* to access ROM past 2k. The remaining 2-bits are supplied by bits-3:4 of the PCLATH register. These must be set or cleared before an assembler GOTO or CALL instruction is implemented within your code. For example, if a portion of your assembler code crosses a boundary, then a call or jump to a routine within that bank will not actually get there. If, however, the ever popular 16F84 is used, then these issues do not arise. However, if the mid-range PIC's are used, then ALL assembler subroutines should be placed at the start of your program, thus ensuring they will be located within bank-0.

Experimenting with the PicBasic Pro Compiler

In order to access your assembler subroutine from BASIC, the compiler's CALL command should always be used. This manipulates the PCLATH register to construct the full 13-bits required to access ROM anywhere in the PIC. The CALL command differs from the GOSUB command in that an underscore must precede the subroutine's name when it is first declared: -

```
Call   My_Sub              ' Call the subroutine My_Sub

Asm
_My_Sub                    ; Note the underscore, _My_Sub
{ Your subroutine goes here }
     Return                ; Exit the subroutine
Endasm
```

The RETURN instruction does not require that the PCLATH is manipulated, as it has access to the full 13-bit address, which it pulls from the *stack*.

Note: when assembler mode has been entered, the comment symbol must change to a semicolon (;) instead of a quote ('). If this is forgotten, then a screen full of extremely confusing errors will be displayed.

Declaring Variables for use with Assembler

Another important issue when designing assembler routines is the use of variables. ALL variables should be declared in BASIC, as the compiler will not recognize assembler declared types. In fact, declaring any variable in assembler will wreak havoc with your program, the assembler does not recognize compiler variables, and the compiler does not recognize assembler variables. So imagine what would happen if (when!) they were both assigned to the same RAM location?

In most cases, when using PICs with more than 2k of ROM, (*and a select few with less*), user RAM is split into several banks. Therefore, all variables used in any assembler routine should be assigned to bank-0. Each RAM bank is 128 bytes apart, these also incorporate the PIC's hardware registers. Bits-5:6 of the STATUS register control which bank the PIC is pointing to.

Experimenting with the PicBasic Pro Compiler

If the compiler assigns a variable that we are using for an assembler routine to a bank other than bank-0, the subroutine has no way of knowing this, therefore, any references to this variable would be pointing to an entirely different location.

When writing purely in BASIC, the compiler takes care of this issue for us, which means that it doesn't care what bank it assigns a particular variable to. In most cases, if a small program is being developed on a larger PIC, the compiler will assign the first lot of variables to bank-0 automatically, until it must move to another bank. However, we cannot be 100% certain that the variables used in our assembler subroutine will always be located in bank-0. So we must force the compiler to assign a particular variable into bank-0, this is accomplished by using the BANK operand after declaring the variable: -

My_Var   Var   Byte   BANK0   ' Assign My_Var to Bank-0

If for any reason, you wish the variable to be located into another bank then BANK1, BANK2, or BANK3 will do just that.

Using the DEFINE command to pass parameters.

A very useful way of passing parameters to an assembler subroutine is with the DEFINE statement. The use of DEFINE is restricted to values that will remain constant throughout the program (*i.e. the port and bit where an infrared sensor is attached*), as the same define may only be used once within the code. This is usually placed at the beginning of the program. As an example, let's suppose we have written a subroutine to output an infrared signal to an LED connected to PortA.1.

```
Define   IR_PORT  PORTA      ' Port on which to attach IR LED
Define   IR_BIT        1     ' Bit on which to attach IR LED

Asm
#Define   IR_LED    IR_PORT , IR_BIT
Endasm
```

Experimenting with the PicBasic Pro Compiler

The #DEFINE is an assembler directive, its use is the same as its BASIC counterpart, as in the example above, every time the name IR_LED is encountered it will be replaced by the string IR_PORT,IR_BIT, and as IR_PORT has been given the value of PORTA (5), and IR_BIT has been given the value 1, the name IR_LED is now equal to the string PORTA,1.

This is used as an interface between BASIC and assembler. And can be placed in the assembler routine like this: -

@	Bcf	IR_LED	; *Clear the appropriate Port and Bit*
@	Bsf	STATUS , 5	; *Point to BANK1 registers*
@	Bcf	IR_LED	; *Make the Port and Bit an OUTPUT*
@	Bcf	STATUS , 5	; *Back to BANK0 registers*
@	Bsf	IR_LED	; *Turn on the IR_LED*

Default values can also be created in case the DEFINE is not used or not required. In the case of our example, lets suppose that the defines are not used, the defaults will be PORTA and BIT-0. For this we use the assembler's IFDEF, IFNDEF, and ENDIF statements. IFDEF, as its name implies, will return true if the #DEFINE has been declared, IFNDEF will return true if the #DEFINE has not been declared. We can use this (*conditional assembly*) to set the port and bit definitions to their default values if the define has not been included in the program like this: -

Asm	; *We are now in assembler mode*
Ifndef IR_PORT	; *Check if IR_PORT has been declared*
IR_PORT = PortA	; *If not, then IR_PORT = PORTA*
Endif	; *End of IF statement*
Ifndef IR_BIT	; *Check if IR_BIT has been declared*
IR_BIT = 0	; *If not, then IR_BIT = 0*
Endif	; *End of IF statement*
Endasm	; *Back to BASIC mode*

This is a very useful and efficient way of passing parameters, as the compiler itself proves with the LCD, DEBUG, SERIN2 etc, defines. And is used in many of the programs throughout this book.

Experimenting with the PicBasic Pro Compiler

Using INCLUDE files to tidy up your code

Include files are also used extensively throughout this book. It aids in the readability of the code and is an easy way to incorporate commonly used subroutines. Include files are by no means a new idea; they have been used since the first assemblers were developed, and are used a lot in languages such as C and PASCAL. However, most people consider the PBP to be just another version of the BASIC Stamp and write code in its style. This could not be further from the truth; it is true that most BASIC Stamp and BASIC Stamp II programs may be directly compiled. But if you are writing purely with the PBP then Stamp code can be awkward and clumsy.

If the include file contains assembler subroutines then it must always be placed at the beginning of the program, just after the **MODEDEFS.BAS** file. This allows the subroutine/s to be placed within the first bank of memory (*0..2048*), thus avoiding any bank boundary errors. Placing the include file at the beginning of the program also allows all of the variables used by the routines held within it to be pre-declared. This again makes for a tidier program, as a long list of variables is not present in the main program.

There are some considerations that must be taken into account when writing code for an include file, these are: -

1). Always jump over the subroutines.

When the include file is placed at the top of the program this is the first place that the compiler starts, therefore, it will run the subroutine/s first and the RETURN command will be pointing to a random place within the code. To overcome this, place a GOTO statement just before the subroutine starts. For example: -

```
    Goto  OVER_THIS_SUBROUTINE        ' Jump over the subroutine
' The subroutine is placed here
    OVER_THIS_SUBROUTINE:             ' Jump to here first
```

2). Variable and Label names should be as meaningful as possible.

For example. Instead of naming a variable **LOOP**, change it to **ISUB_LOOP**. This will help eliminate any possible duplication errors, caused by the main program trying to use the same variable or label name. However, try not to make them too obscure as your code will be harder to read and understand, it might make sense at the time of writing, but come back to it after a few weeks and it will be meaningless.

3). Comment, Comment, and Comment some more.

This cannot be emphasized enough. ALWAYS place a plethora of remarks and comments. The purpose of the subroutine/s within the include file should be clearly explained at the top of the program, also, add comments after virtually every command line, and clearly explain the purpose of all variables and constants used. This will allow the subroutine to be used many weeks or months after its conception. A rule of thumb that I use is that I can understand what is going on within the code by reading only the comments to the right of the command lines.

The include file used by your program must be in the same directory as that program, or in the root directory of the compiler (*i.e. PBASIC*).

There are some things that should NOT be done inside an include file. These are: -

DO NOT load in the **MODEDEFS.BAS** include file. Always place this in the main program.
DO NOT use the OSC define, as this may override the OSC setting within the main program.

Experimenting with the PicBasic Pro Compiler

Waking the PIC from SLEEP

All the PICmicro range have the ability to be placed into a low power mode, consuming micro Amps of current.

The command for doing this is SLEEP. The compiler's SLEEP command or the assembler's SLEEP instruction may be used. The compiler's SLEEP command differs somewhat to the assembler's in that the compiler's version will place the PIC into low power mode for *n* seconds (*where n is a value from 0 to 65535*). The assembler's version still places the PIC into low power mode, however, it does this forever, or until an internal or external source wakes it. This same source also wakes the PIC when using the compiler's command.

Many things can wake the PIC from its sleep, the WATCHDOG TIMER is the main cause and is what the compiler's SLEEP command uses. Another method of waking the PIC is an external one, a change on one of the port pins. We will examine more closely the use of an external source.

For these demonstrations the watchdog timer must be disabled or it will wake the PIC every time it *times-out*. This is accomplished by placing the following line of code at the beginning of the program: -

@   Device wdt_off

Note: that this may only be used when the PM assembler is chosen. Also, it is device independent.

There are two main ways of waking the PIC using an external source. One is a change on bits 4..7 of PortB. Another is a change on bit-0 of PortB. We shall first look at the wake up on change of PortB,bits-4..7.

As its name suggests, any change on these pins either high to low or low to high will wake the PIC. However, to setup this mode of operation several bits within registers INTCON and OPTION_REG need to be manipulated. One of the first things required is to enable the weak PortB pullup resistors. This is accomplished by clearing the RBPU bit of OPTION_REG (*OPTION_REG.7*). If this was not done, then the pins would be floating and random input states would occur waking the PIC up prematurely.

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Although technically we are enabling a form of interrupt, we are not interested (*in this program*) in actually running an interrupt handler. Therefore, we must make sure that GLOBAL interrupts are disabled, or the PIC will jump to an interrupt handler every time a change occurs on PortB. This is done by clearing the GIE bit of INTCON (*INTCON.7*).

The interrupt we are concerned with is the RB port change type. This is enabled by setting the RBIE bit of the INTCON register (*INTCON.3*). All this will do is set a flag whenever a change occurs (*and of course wake up the PIC*). The flag in question is RBIF, which is bit-0 of the INTCON register. For now we are not particularly interested in this flag, however, if global interrupts were enabled, this flag could be examined to see if it was the cause of the interrupt. The RBIF flag is not cleared by hardware so before entering SLEEP it should be cleared. It must also be cleared before an interrupt handler is exited.

The SLEEP command itself is then used. Upon a change of PortB, bits 4..7 the PIC will wake up and perform the next instruction (*or command*) after the SLEEP command was used.

A second external source for waking the PIC is a pulse applied to PortB.0. This interrupt is triggered by the edge of the pulse, high to low or low to high. The INTEDG bit of OPTION_REG (*OPTION_REG.6*) determines what type of pulse will trigger the interrupt. If it is set, then a low to high pulse will trigger it, and if it is cleared then a high to low pulse will trigger it.

To allow the PortB.0 interrupt to wake the PIC the INTE bit must be set, this is bit-4 of the INTCON register. This will allow the flag INTF (*INTCON.1*) to be set when a pulse with the right edge is sensed. As with the previous discussion, this flag is only of any importance when determining what caused the interrupt. However, it is not cleared by hardware and should be cleared before the SLEEP command is used (*or the interrupt handler is exited*).

The programs **SLEEP.BAS**, and **SLEEP2.BAS** demonstrate both methods discussed. **SLEEP.BAS** will wake the PIC when a change occurs on PortB, bits 4-7. And **SLEEP2.BAS** will wake the PIC when a pulse is detected on PortB.0.

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A brief introduction to hardware interrupts

There are many ways that interrupts may be triggered on the different types of PIC available. The previous discussion on SLEEP showed two possible methods. However, we do not have the space to go into all the various ways, as some of the larger PICs have more than 30 individual interrupt triggering sources. Therefore, we will examine how to enable interrupts using the most popular method, that of TIMER0.

TIMER0, or TMR0 is an eight-bit register, in its simplest form TMR0 increments with every instruction cycle. When the count reaches 255 it rolls over to 0 and keeps on counting. TMR0 also has a prescaler which may be attached to it. When the prescaler is enabled, TMR0 increments once every 2, 4, 8, 16, 32, 64, 128, or 256 instruction cycles. Whenever TMR0 rolls over to 0 an interrupt may be generated.

The compiler's ON INTERRUPT command is not an interrupt in the true sense of the word as it must finish the BASIC command it is processing before the interrupt handling subroutine is called. True interrupts occur on a regular basis, or are triggered by an event, regardless of what the PIC is processing at the time. Therefore, the ON INTERRUPT command will not be discussed just yet. Instead we will examine true hardware interrupts that occur naturally within the PIC. These, unfortunately must always use assembler within the interrupt handler. The reason behind this is that the compiler's commands are not re-entrant, which means only one command at a time may be used. This sounds like stating the obvious, however, if BASIC commands were used within a hardware interrupt, a command in the main body program could be interrupted mid-stream and the same instruction may be encountered in the interrupt handler. As both commands would be using the same SYSTEM variables, one of the commands is going to be presented with the wrong values. This could lead to major program crashes, or subtle bugs that would be next to impossible to track down.

To inform the compiler where to find the assembler interrupt handling subroutine a Define is used: -

Define   INTHAND   My_Int   *' Point to interrupt handler*

The compiler will now jump to the interrupt handling subroutine **MY_INT** whenever an interrupt is triggered.

Before we can change any bits that correspond to interrupts we need to make sure that global interrupts are disabled. This is done by clearing the GIE bit of INTCON (*INTCON.7*). Sometimes an interrupt may occur while the GIE bit is being cleared, which means that the bit is not actually cleared and global interrupts are not disabled. To make sure that the GIE bit is actually cleared we must poll it. This can be accomplished by a simple loop: -

GIE=0	*' Disable global interrupts*
While GIE=1	*' Make sure they are off*
GIE=0	*' Continue to clear GIE*
Wend	*' Exit when GIE is clear*

The prescaler attachment to TMR0 is controlled by bits 0:2 of the OPTION_REG (*PS0, 1, 2*). Table 1.1 shows their relationship to the prescaled ratio applied. But before the prescaler can be calculated we must inform the PIC as to what clock governs TMR0. This is done by setting or clearing the PSA bit of OPTION_REG (*OPTION_REG.3*). If PSA is cleared then TMR0 is attached to the external crystal oscillator. If it is set then it is attached to the watchdog timer, which uses the internal RC oscillator. This is important to remember; as the prescale ratio differs according to which oscillator it is attached to.

PS2	PS1	PS0	PSA=0 (External crystal OSC)	PSA=1 (Internal WDT OSC)
0	0	0	1 : 2	1 : 1
0	0	1	1 : 4	1 : 2
0	1	0	1 : 8	1 : 4
0	1	1	1 : 16	1 : 8
1	0	0	1 : 32	1 : 16
1	0	1	1 : 64	1 : 32
1	1	0	1 : 128	1 : 64
1	1	1	1 : 256	1 : 128

Table 1.3. TMR0 prescaler ratio configurations.

As can be seen from the above table, if we require TMR0 to increment on every instruction cycle (*4/OSC*) we must clear PS2..0 and set PSA, which would attach it to the watchdog timer. This will cause an interrupt to occur every 256us (*assuming a 4mHz crystal*). If the same values were placed into PS2..0 and PSA was cleared (*attached to the external oscillator*) then TMR0 would increment on every 2nd instruction cycle and cause an interrupt to occur every 512us.

There is however, another way TMR0 may be incremented. By setting the T0CS bit of the OPTION_REG (*OPTION_REG.5*) a rising or falling transition on PortA.0 will also increment TMR0. Setting T0CS will attach TMR0 to PortA.0 and clearing T0CS will attach it to the oscillators. If PortA.0 is chosen then an associated bit, T0SE (*OPTION_REG.4*) must be set or cleared. Clearing T0SE will increment TMR0 with a low to high transition, while setting T0SE will increment TMR0 with a high to low transition.

The prescaler's ratio is still valid when PortA.0 is chosen as the source, so that every n^{th} transition on PortA.0 will increment TMR0. Where *n* is the prescaler ratio.

Before the interrupt is enabled, TMR0 itself should be assigned a value, as any variable should be when first starting a program. In most cases clearing TMR0 will suffice. This is necessary because, when the PIC is first powered up the value of TMR0 could be anything from 0 to 255

We are now ready to allow TMR0 to trigger an interrupt. This is accomplished by setting the T0IE bit of INTCON (*INTCON.5*). Setting this bit will not cause a global interrupt to occur just yet, but will inform the PIC that when global interrupts are enabled, TMR0 will be one possible cause. When TMR0 overflows (*rolls over from 255 to 0*) the T0IF (*INTCON.2*) flag is set. This is not important yet but will become crucial in the interrupt handler subroutine.

The final act is to enable global interrupts by setting the GIE bit of the INTCON register (*INTCON.7*).

The interrupt handler subroutine must always follow a fixed pattern. First, the contents of the W register along with PCLATH and STATUS must be saved, this is termed *context saving*. Therefore, we need to set aside several variables for the registers to be stored into: -

```
Wsave    Var  Byte      SYSTEM  ' Storage for the W register
Ssave    Var  Byte      SYSTEM  ' Storage for the STATUS reg
Psave    Var  Byte      SYSTEM  ' Storage for the PCLATH reg
```

The actual assembly code placed at the head of the interrupt handler that does the context saving is: -

```
Asm
My_Int                              ; The name of the interrupt
        Movwf   Wsave               ; Save the W register
        Swapf   STATUS,w
        Clrf    STATUS
        Movwf   Ssave               ; Save the STATUS register
        Movf    PCLATH,w
        Movwf   Psave               ; Save the PCLATH register
{ Your interrupt code goes here }
```

Saving of the registers is done automatically by the compiler if a PIC with more than 2k of ROM is used. However, when using PICs with more than 2K things get a little trickier, as more storage space is required along with their ADDRESS and BANK positions. The reasoning behind this is that when an interrupt occurs, the PIC might be processing commands in a bank other than bank-0, which also means that the RAM addresses have moved to another bank. If the W register was now to be saved into the variable **WSAVE** prior to processing the interrupt code, it would be pointing to the correct location in RAM but the wrong bank.

The data memory (*RAM*) is organised in banks of 128. In the case of the new PIC16F87X range the first bank of memory (*bank0*) starts at address $20, the second at $A0, the third (*if it has more than 2 banks*) at $120, and the fourth (*if it has more than 3 banks*) at $1A0. Therefore, if the interrupt was called while the PIC was processing code in bank-1, then what used to be RAM address $20 is now actually $A0. If a variable was already assigned to $A0 its contents would be overwritten by the interrupt placing the contents of W into it.

To be extra safe, the address of the **WSAVE** variables along with their bank locations should be used. The address location should be the same for each bank. For example: -

Experimenting with the PicBasic Pro Compiler

Wsave0	Var	$20	BANK0	SYSTEM	' W storage in bank-0
Wsave1	Var	$A0	BANK1	SYSTEM	' W storage in bank-1
Wsave2	Var	$120	BANK2	SYSTEM	' W storage in bank-2
Wsave3	Var	$1A0	BANK3	SYSTEM	' W storage in bank-3
Ssave	Var	Byte	BANK0	SYSTEM	' STATUS storage
Psave	Var	Byte	BANK0	SYSTEM	' PCLATH storage

This will allow the W register to be saved at the first location of RAM in any bank regardless of which bank the PIC was in when the interrupt was called. If it is processing bank-1 then the W register will be saved into the variable **WSAVE1** as well as **WSAVE0**.

Note. This only applies when using interrupts, as the compiler normally takes the headache out of bank switching.

When the interrupt handler was called the GIE bit was automatically cleared by hardware, disabling any more interrupts. If this were not the case, another interrupt might occur while the interrupt handler was processing the first one, which would lead to disaster.

Now the TOIF (*TMR0 overflow*) flag becomes important. Because, before exiting the interrupt handler it must be cleared to signal that we have finished with the interrupt and are ready for another one. Also the W, PCLATH and STATUS registers must be returned to their original conditions. The assembler code for doing this is: -

```
{ Your interrupt code goes here }
    Movf      Psave,w          ; Restore PCLATH register
    Movwf     PCLATH
    Swapf     Ssave,w          ; Restore STATUS register
    Movwf     STATUS
    Swapf     Wsave,f
    Swapf     Wsave,w          ; Restore W register
```

The final command in the interrupt handler returns the PIC back to the main body code where the interrupt was called from. RETFIE must be used as opposed to RETURN because, RETFIE also re-enables global interrupts.

A simplistic yet typical interrupt handling subroutine is shown below for use on PICs with 2k or less of ROM: -

```
Asm
INT
      Movwf     Wsave            ; Save the registers
      Swapf     STATUS,w         ; Before starting the code
      Clrf      STATUS           ; Within the interrupt handler
      Movwf     Ssave
      Movf      PCLATH,w
      Movwf     Psave

      Movlw 255
      Xorwf PortB                ; Flash an LED every interrupt

      Bcf       INTCON,T0IF      ; Clear the TMR0 overflow flag
      Movf      Psave,w
      Movwf     PCLATH
      Swapf     Ssave,w          ; Restore the registers
      Movwf     STATUS           ; Before exiting the Interrupt
      Swapf     Wsave,f
      Swapf     Wsave,w
      Retfie                     ; Exit the interrupt subroutine
Endasm
```

The program above is the classic flashing led program implemented the long way. Every time the interrupt is called the Xorwf instruction will turn the led on or off. The flashing will only be apparent if the prescaler ratio is assigned a high value, such as 1:256.

To make life easier when using hardware interrupts, three include files have been developed. **2K_INT.INC**, is for use with PICs that have 2k or less of ROM, such as the 16F84. **4K_INT.INC**, is for use with PICs that have 4k of ROM, such as the 16F874 . And **8K_INT.INC**, is for use with PICs that have 8k of ROM, such as the 16F877.

The chosen include file, as always, must be placed at the beginning of your program. Within each include file the exact amount of variable space is allocated for context saving, also two macros are defined. The reason behind developing three include files instead of a one-for-all approach is that it is less wasteful on precious variable space.

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The first macro, **INT_START**, saves the W register along with the STATUS and PCLATH. This macro is only required when using a PIC with 2k or less of ROM, as the compiler automatically saves the context for larger PICs. To use the **INT_START** macro, place the following template code at the beginning of your interrupt handler: -

```
Asm
My_Int                          ; The name of the interrupt
      INT_START                 ; Use the context saving macro
{ Your interrupt handling code goes here }
```

The second macro, **INT_END**, restores the contents of the W register, STATUS, and PCLATH, then performs a RETFIE instruction. This macro must be used regardless of the PIC size, as the compiler does not restore the context for larger PICs. To use the **INT_END** macro, place the following template code at the end of your interrupt handler: -

```
{ Your interrupt handling code goes here }
      INT_END                   ; Use the context restore macro
Endasm
```

Each macro defined in the separate include files uses exactly the right amount of instructions according to the size of the PIC chosen. Thus reducing wasted memory

The program **TMR0CLCK.BAS** demonstrates the use of a TMR0 interrupt performing the functions of a (*not very accurate*) clock, displaying the time on a serial LCD connected to PortA.0. The prescaler is assigned the ratio of 1:64, which means that an interrupt will be called every 16.384ms (*64*256us*). Assuming a 4mHz crystal is used.

Each time the interrupt is called, the variable **TICKS** is incremented until it reaches 61. This will give us an approximate second (*61*16384 = 999.424ms or .999424 of a second*).

When **TICKS** reaches 61, a second has past so the **SECONDS** variable is incremented and the **TICKS** variable is cleared. When **SECONDS** reaches 60, a minute has passed so the **MINUTES** variable is incremented and the **SECONDS** variable is cleared. When **MINUTES** reaches 60, an hour has passed so the **HOURS** variable is incremented and the **MINUTES** variable is cleared.

And finally, when the **HOURS** variable reaches 23 then a full 24-hour day has passed so **HOURS** is cleared. If more than a second has passed then the flag **U_FLAG** is set. This will inform the main program loop to update its display with the current time.

It must be noted that TMR0 itself is enabled at power up. Regardless of whether the T0IE bit is set or not. This just attaches it to an interrupt. Which means that the T0IF flag will always be set when an overflow occurs.

In addition, when the prescaler is attached to the watchdog timer, the compiler's SLEEP and NAP commands may not be used. As these are also attached to the watchdog, and rely on the prescaler's ratio.

The code within the interrupt handler should be quick and as efficient as possible because, while it's processing the code the main program is halted.

When using assembler interrupts, care should be taken to ensure that the watchdog timer does not *time-out*. Placing a CLRWDT instruction at regular intervals within the code will prevent this from happening. An alternative approach would be to disable the watchdog timer altogether, as illustrated in the SLEEP discussion.

Using the ON INTERRUPT command

Using the ON INTERRUPT command is similar to using an assembler interrupt. However, the compiler does not immediately call the interrupt handler, instead it flags it and waits until the command being processed is finished. As there might be a delay before the interrupt is called, the prescaler's ratio should not be assigned too low a value. For example, if the prescaler was assigned the ratio 1:1, then an interrupt should occur every 256us (*assuming a 4mHz oscillator*). However, if the compiler has to wait until the current command is finished, it might not have time to process the interrupt at the instant TMR0 rolled over.

Things become trickier if a change of state on the port pins is triggering the interrupt. By the time the interrupt handler has been called, the event that triggered it could have already finished.

However, it does have its advantages, especially if a non time-critical interrupt is being implemented, as it will not slow down the PIC while a serial or pause command is being used. Also, it does not require different code for the various sizes of PIC. Which means the code produced should work on any type.

To use the ON INTERRUPT command with a TMR0 interrupt, the same bits of INTCON and OPTION_REG must be set or cleared, as in the previous discussion. However, instead of using the INTHAND define to point to the interrupt handling subroutine, the ON INTERRUPT command is used: -

ON INTERRUPT GOTO   My_Int   ' Point to the interrupt handler

The interrupt handler itself also differs from the assembler type. Unlike hardware interrupts, the compiler's version of an interrupt simply places a call to the interrupt handler before each command is processed. Upon entering the interrupt subroutine, these calls must be disabled. This is the job of the DISABLE command. DISABLE isn't really a command at all, it is actually a directive that informs the compiler to disable the interrupt flagging process. It serves the same purpose as clearing the GIE bit in hardware interrupts. On the same note, the GIE bit is actually cleared when a compiler interrupt is called. This in turn disables interrupts occurring within interrupts.

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The DISABLE directive should be placed at the head of the interrupt handling subroutine: -

DISABLE
My_Int
{ Interrupt handler starts here }

The W, STATUS, and PCLATH temporary storage variables do not need to be declared, as the compiler does this for us, regardless of the size of the PIC.

The code differs on exiting the interrupt handler as well. The RETFIE instruction is not used; instead it is replaced by the RESUME command. This does a similar job as the assembler's RETFIE instruction in that it re-enables global interrupts. The ENABLE directive must be issued after the RESUME command to inform the compiler to start flagging the commands again: -

{ Interrupt handler ends here }
RESUME
ENABLE

The W, STATUS, and PCLATH values do not need to be restored as they did in the assembler interrupt; the compiler also does this for us.

There are certain guidelines that should be adopted when using the compiler's interrupt, that don't apply to an assembler type. Because the compiler must finish each command before processing an interrupt, certain commands must be re-arranged. One such command is PAUSE. If a delay of 1 second were required, the normal procedure would be: -

Pause 1000

But this will cause the PIC to wait 1000ms before it can process its interrupt handler.

A better solution would be to break up the delay into smaller amounts: -

For X = 0 to 10000
Pauseus 100
Next

This will give us the same 1 second delay and allow the interrupt handler to be called regularly. The same method should be adopted when using the more complex commands, such as SEROUT, SERIN, PULSIN etc, as a lot of these commands disable interrupts while they are working.

In the case of SEROUT or one of its relatives, instead of sending data all in one command, split it into several SEROUT commands. When using SERIN type commands, always place a time-out value within them, shorter than the interrupt's interval time. Otherwise no interrupt will occur while the PIC is waiting for the serial data to arrive.

The demonstration program **INT_CLK.BAS** has exactly the same function as the assembler program, **TMR0CLK.BAS,** in that it implements a clock displaying the time on a serial LCD. In fact, the main body of the code is identical; only written in BASIC. The main differences are the DISABLE, ENABLE, and RESUME commands used within the handler. And the use of the ON INTERRUPT command as opposed to the INTHAND define.

While studying both the hardware and the compiler's interrupts, you should see a pattern emerging concerning the INTCON register. Control bits that end with an 'E', such as T0IE, enable or disable an interrupt. While those that end with an 'F', such as T0IF, inform the PIC as to whether an event has occurred or not. This fundamental pattern holds true for all other interrupt registers as well.

Section-11

Powering up the PIC

Getting the most out of batteries.
The perfect Power-up.

Getting the most out of batteries

Battery power is necessary when designing portable projects, but batteries have a tendency to decrease in voltage as they age. Besides, who ever heard of a five volt battery?

Placing three *AA* or *AAA* cells in series will provide only 4.5V (*3.6V for nicads*), which will cause problems for most PICs. And using four cells will produce 1V too many, causing the PIC to generate heat. What is required is a means of producing the correct voltage at a constant rate throughout the battery's lifetime. Enter the switch mode converter.

Until recently switch mode converters were not for the faint hearted. But now a vast array of off the shelf devices are readily available. Maxim seems to be the most prolific designer of these devices, with all shapes and voltages available.

The device we shall look at first is Maxim's MAX777 step-up converter. It can provide an output voltage of 5V from an input as low as 1.5V, and output currents in excess of 200mA are possible (*only with a 4.5V input*). High speed switching allows the use of small inductors and decoupling capacitors. It draws only 190uA of quiescent current when operating and an amazing 20uA when disabled, which makes it ideal for battery operation.

Figure 11.1 shows a typical application circuit for providing 5V from a 4.5V source (*three AA or AAA cells*).
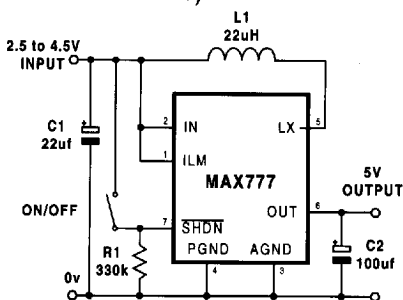

Figure 11.1. MAX777, 5 Volt switch mode converter.

When the SHDN pin is pulled high the chip is enabled. R1 ensures that SHDN is pulled low when the on/off switch is open.

The next switch mode device we shall look at is Maxim's MAX761. This is capable of producing a variable output voltage between 5V and 16.5V from an input voltage of 4.75V to 12V, provided the input voltage is less than the required output voltage. The MAX761 is capable of producing an output current in excess of 150mA. If that wasn't enough, the device also has an on-board low voltage detector.

Figure 11.2 shows a circuit to provide a 5V output using a 4.5V input.
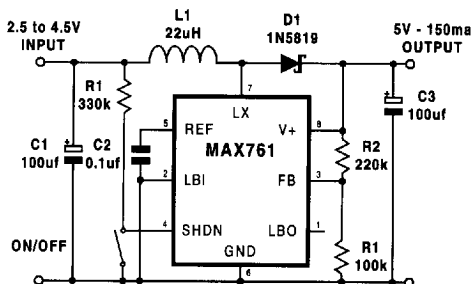

Figure 11.2. MAX761, 5 Volt switch mode converter.

Resistors R1 and R2 set the appropriate output voltage. The resistors are calculated using the formula: -

$$R2 = R1 * ((Vout / 1.5) - 1))$$

The value of R2 can be anywhere between 10kΩ and 250kΩ, remember, the higher the value of these two resistors, the lower the current loss through them.

The value of the inductor (L1) must also be calculated for different input voltages. The formula for this is: -

$$L(uH) = 5 * Vin$$

The diode D1 must be a high speed Schottky rectifier. A normal 1N4001 will not work as a replacement as it is not capable of operating at the required high frequencies.

By changing the value of R1, R2 and L1, higher output voltages can be achieved. Figure 11.3 shows circuit for producing 9V from four AAA or AA cells (6V).
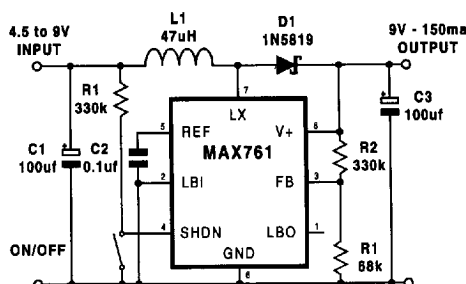
Figure 11.3. MAX761, 9 Volt switch mode converter.

Battery monitoring is achieved by adding two resistors and an indicating LED. Figure 11.4 shows a circuit that produces 5V from a three AAA or AA cells and illuminates the LED when the voltage from these drops below 3V.
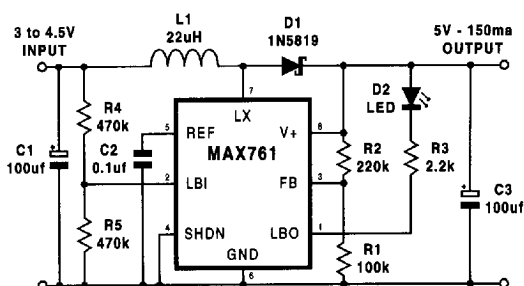

Figure 11.4. 5 Volt output with battery monitoring.

Resistors R4 and R5 set the trip voltage. They are calculated using the formula: -

$$R4 = R5 * ((Vtrip - 1.5) / 1.5)$$

R5 must have a resistance between 10kΩ and 500kΩ. The LBO pin could also be connected to one of the PIC's pins, indicating that a possible shutdown is imminent.

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To use a battery such as the PP3 9V type to supply 5V, a regulator such as the 78XX series are normally employed to reduce the voltage. However, these types of regulators are as inefficient as they are inexpensive. The voltage IN/OUT difference is wasted as heat.

A more efficient method uses switch mode techniques to reduce the voltage. Figure 11.5 shows such a circuit for producing 5V from a 9V battery with currents up to 450mA available. Using the MAXIM device MAX738A.
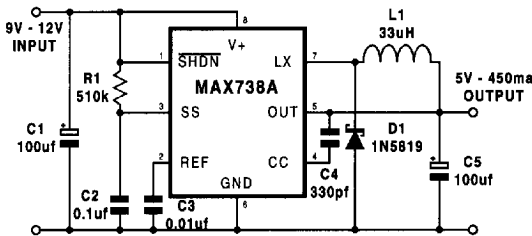

Figure 11.5. Step down switch mode converter.

As in the previous switch converters, the rectifier D1 must be a Schottky type.

Using the above circuits will extract the last drops of energy from expensive batteries, with up to 96% efficiency.

The perfect Power-up.

Although most PICs have a built in power-up timer (*PWRT*) of 72ms, which is supposed to prevent them from not starting up if the power supply takes to long to stabilise. Sometimes it is not enough of a delay and the PIC needs to be manually reset. The mid-range PICs such as the new 16F876 have additional brown out protection circuits built in which help over come the inadequacies of the PWRT.

To ensure that the PIC always starts, an external brown out device is required. These monitor the supply voltage until the required threshold is reached then release the MCLR line.

One such device is the Dallas semiconductors DS1810. This is a simple and inexpensive 3-pin device that looks like a TO92 transistor. The MCLR pin is held low until a supply voltage of approximately 4V is reached. At which time the DS1810 delays for a further 150ms before bringing its RST pin high and releasing MCLR.

Figure 11.5 illustrates how extremely simple these devices are to connect to the PIC.
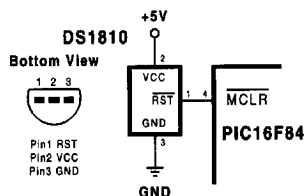

Figure 11.5. DS1810 Brownout circuit.

The DS1810 also resets the PIC if the voltage drops below approx 4V, thus eliminating any errors that might occur within the PICs memory due to low voltage.

Appendix

Component suppliers.

All the components used within this book are available from Crownhill Associates

http://www.crownhill.co.uk

In the unlikely event that Crownhill does not have the item/s in stock, the following suppliers may be able to assist: -

FARNELL.   **http://www.farnell.com**

MAPLIN Electronics.   **http://www.maplin.co.uk**

RS Components.   **http://www.rswww.com**

The PicBasic Pro Compiler and it's upgrades may also be purchased from Crownhill Associates, picbasic web site.

http://www.picbasic.co.uk.

Or directly from microEngineering, Labs Inc.

http://www.melabs.com.

Thanks also to Crownhill, there is now a PicBasic email list.

This list allows PicBasic and PicBasic Pro Compiler owners to compare notes and share programming tips with each other.

To add your email address to the list send a message to: -
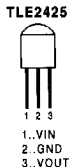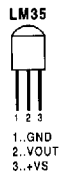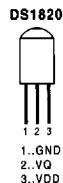
majordomo@qunos.net

In the message body enter: -

subscribe PICBASIC-L

This will then reply with a message to verify your email address and ask you to reply. Once this is done, messages may be sent to: -

picbasic-l@qunos.net

Device pinouts.

24C32
1	A0	VCC	8
2	A1	WP	7
3	A2	SCL	6
4	VSS	SDA	5

25LC640
1	CS	VCC	8
2	SO	HOLD	7
3	WP	SCLK	6
4	VSS	SI	5

93C66
1	CS	VCC	8
2	SK	N.C.	7
3	DI	ORG	6
4	DO	VSS	5

TL082/LMC662
1	OUT1	V+	8
2	-IN1	OUT2	7
3	+IN1	-IN2	6
4	GND	+IN2	5

MAX187
1	VDD	SCLK	8
2	AIN	CS	7
3	SHDN	DOUT	6
4	REF	GND	5

MAX5352
1	OUT	VDD	8
2	CS	GND	7
3	DIN	REF	6
4	SCLK	FB	5

MAX761
1	LBO	V+	8
2	LBI	LX	7
3	FB	GND	6
4	SHDN	REF	5

MAX777
1	ILIM	N.C.	8
2	IN	SHDN	7
3	AGND	OUT	6
4	PGND	LX	5

ICL7660
1	BOOST	V+	8
2	CAP+	OSC	7
3	GND	LV	6
4	CAP-	VOUT	5

AD8400
1	B1	A1	14
2	GND	W1	13
3	CS	VDD	12
4	SDI	CLK	11

AD8402
1	AGND	B1	14
2	B2	A1	13
3	A2	W1	12
4	W2	VDD	11
5	DGND	RS	10
6	SHDN	CLK	9
7	CS	SDI	8

AD8403
1	AGND2	B1	24
2	B2	A1	23
3	A2	W1	22
4	W2	AGND1	21
5	AGND4	B3	20
6	B4	A3	19
7	A4	W3	18
8	W4	AGND3	17
9	DGND	VDD	16
10	SHDN	RS	15
11	CS	CLK	14
12	SDI	SDO	13

MAX127
1	VDD	N.C.	28
2	VDD	REF	27
3	DGND	REFADJ	26
4	N.C.	N.C.	25
5	SCL	N.C.	24
6	A0	CH7	23
7	N.C.	N.C.	22
8	N.C.	CH6	21
9	SDA	CH5	20
10	A2	CH4	19
11	N.C.	CH3	18
12	A1	CH2	17
13	SHDN	CH1	16
14	AGND	CH0	15

MAX7219
1	DIN	DOUT	24
2	DIG-0	SEG-D	23
3	DIG-4	SEG-DP	22
4	GND	SEG-E	21
5	DIG-6	SEG-C	20
6	DIG-2	V+	19
7	DIG-3	ISET	18
8	DIG-7	SEG-G	17
9	GND	SEG-B	16
10	DIG-5	SEG-F	15
11	DIG-1	SEG-A	14
12	LOAD	CLK	13

MAX186
1	CH0	VDD	20
2	CH1	SCLK	19
3	CH2	CS	18
4	CH3	DIN	17
5	CH4	SSTRB	16
6	CH5	DOUT	15
7	CH6	DGND	14
8	CH7	AGND	13
9	VSS	REFADJ	12
10	SHDN	VREF	11

L293D
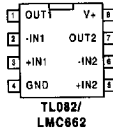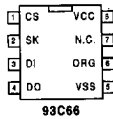| 1 | ENABLE1 | VSS | 16 |
2	IN1	IN4	15
3	OUT1	OUT4	14
4	GND	GND	13
5	GND	GND	12
6	OUT2	OUT3	11
7	IN2	IN3	10
8	VS	ENABLE2	9

78L05
1..VIN
2..GND
3..VOUT

DS1810
1..RST
2..VCC
3..GND

DS1820
1..GND
2..VQ
3..VDD

LM35
1..GND
2..VOUT
3..+VS

TLE2425
1..VIN
2..GND
3..VOUT

Device pinouts (continued)

	PIC16F84		
1	RA2	RA1	18
2	RA3	RA0	17
3	RA4/RTCC	OSC1/CLKIN	16
4	MCLR	OSC2/CLKOUT	15
5	VSS	VDD	14
6	RB0/INT	RB7	13
7	RB1	RB6	12
8	RB2	RB5	11
9	RB3	RB4	10

PIC16F84

	ISD1416		
1	A0	VCCD	28
2	A1	REC	27
3	A2	XCLK	26
4	A3	REC LED	25
5	A4	PLAYE	24
6	A5	PLAYL	23
7	N.C.	N.C.	22
8	N.C.	ANA OUT	21
9	A6	ANA IN	20
10	A7	AGC	19
11	N.C.	MIC REF	18
12	VSSD	MIC	17
13	VSSA	VCCA	16
14	SP+	SP-	15

ISD1416

	PIC16F873/6		
1	MCLR/VPP/THV	RB7/PGD	28
2	RA0/AN0	RB6/PGC	27
3	RA1/AN1	RB5	26
4	RA2/AN2/Vref-	RB4	25
5	RA2/AN3/Vref+	RB3/PGM	24
6	RA4/TOCKI	RB2	23
7	RA5/AN4/SS	RB1	22
8	VSS	RB0/INT	21
9	OSC1/CLKIN	VDD	20
10	OSC2/CLKOUT	VSS	19
11	RC0/T1OSO/T1CKI	RC7/RX/DT	18
12	RC1/T1OS1/CCP2	RC6/TX/CK	17
13	RC2/CCP1	RC5/SDO	16
14	RC3/SCK/SCL	RC4/SDI/SDA	15

PIC16F873 / 6

BC547/9

TIP31/32

C B E

B C E

	PIC16F874/7		
1	MCLR/VPP/THV	RB7/PGD	40
2	RA0/AN0	RB6/PGC	39
3	RA1/AN1	RB5	38
4	RA2/AN2/Vref-	RB4	37
5	RA2/AN3/Vref+	RB3/PGM	38
6	RA4/TOCKI	RB2	35
7	RA5/AN4/SS	RB1	34
8	RE0/RD/AN5	RB0/INT	33
9	RE1/WR/AN6	VDD	32
10	RE2/CS/AN7	VSS	31
11	VDD	RD7/PSP7	30
12	VSS	RD6/PSP6	29
13	OSC1/CLKIN	RD5/PSP5	28
14	OSC2/CLKOUT	RD4/PSP4	27
15	RC0/T1OSO/T1CKI	RC7/RX/DT	26
16	RC1/T1OS1/CCP2	RC6/TX/CK	25
17	RC2/CCP1	RC5/SDO	24
18	RC3/SCK/SCL	RC4/SDI/SDA	23
19	RD0/PSP0	RD3/PSP3	22
20	RD1/PSP1	RD2/PSP2	21

PIC16F874 / 7

CDROM Contents.

The source code for the program demonstrations used in the book may be found in the **SOURCE** directory. Each section has its own sub-directory, and each experiment has further sub-directories.

For example. To find the **MAX_CNT.BAS** program from Section-1, Interfacing with the MAX7219. Open the **SOURCE** directory, then the **DISPLAYS** directory and the program will be found in the **MAX7219** directory.

The Semiconductor datasheets for the devices used throughout the book may be found in the **DATASHEETS** directory. Each type of device is separated into their own category by the use of sub-directories.

Further application notes for various related devices may be found in the **EXTRAS** directory.

Again, I thank you for purchasing this book.

Remember to look out for further Supplements and Projects on the Rosetta Technologies web site: -

http://www.rosetta-technologies.co.uk

Alternatively, contact me directly on

rosetta@technologies.fsbusiness.co.uk

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